Investigation of Reciprocal Cross Effects in F2 Nellore–Angus Calves

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Abstract: The objectives of this study were to analyze calf performance traits and sex ratio frequencies in reciprocal Bos indicus–Bos taurus F2 Nellore–Angus calves (n = 539). The F2 calves were produced using reciprocal Angus-sired (AN) and Nellore-sired (NA) F1 sires and F1 dams, resulting in four F2 cross types. Calf weight traits were analyzed using mixed models. Deviations from 50% calf sex ratios were tested against expected binomial thresholds. Dam type influenced Julian birth date (p < 0.05) with calves from AN cows born 5 to 6 days earlier than calves from NA cows. Sire type and dam type affected birth weight (p < 0.05) with calves from NA parents approximately 2.5 kg heavier than those from AN parents; weaning weight did not differ for parent F1 type. However, an interaction between sire and dam types affected weaning weight (p = 0.038) where AN x AN calves were 5 to 8 kg lighter than other crosses. Sire type influenced calf sex distribution at birth (p = 0.036) and at weaning (p = 0.026) with NA sires producing over 66% male calves. These results suggest birth weight reciprocal differences due to parental line of descent typically observed among F1 Bos indicus–Bos taurus crosses can persist in subsequent generations.

Keywords: Bos indicus–Bos taurus crosses; birth date; birth weight; calf growth; calf sex ratio

1. Introduction

Crossbred cattle are popular among commercial producers due to their combined breed characteristics and hybrid vigor (increased performance of crosses compared to purebred averages), particularly for lowly heritable traits such as reproduction and health. In tropical and subtropical regions, many crosses involve Bos indicus and Bos taurus breeds. First generation (F1) crosses of these subspecies are exceptionally valuable for calf production and reproductive longevity of females for example [1–3]. However, producing F1 crosses greatly increases birth weight when Bos indicus sires are mated with Bos taurus dams, with males much larger than females as opposed to other sire breeds [4–7]. Studies have shown large reciprocal differences for F1 Bos indicus–Bos taurus crosses in calf birth weight [8–11]. For example, Brown et al. [9] found that among F1 Angus–Brahman calves, those from Angus sires weighed less at birth than those from Brahman sires by 7.4 kg (31.0 kg vs. 38.4 kg) in heifer calves and 13.7 kg (32.1 kg vs. 45.8 kg) in bull calves. These reciprocal birth weight differences have not been attributed to simple maternal effects as they have also been documented in embryo transfer calves from recipient females of different breed types than the calves [11,12].

Much less is known about reciprocal differences among F2 crosses involving Bos indicus and Bos taurus because previous datasets have combined multiple types of F1 (Bos indicus-sired vs. Bos taurus-sired) or F2 crosses into single classes based on assumptions from the genetic dominance model for heterosis, which is based on relative breed heterozygosity [13]. Early research in Queensland, Australia and Florida, USA that used Brahman and British and/or Continental breeds to make crossbred cattle indicated that how the F2 cows are created (i.e., having a Bos indicus-sired sire versus a Bos taurus-sired sire) may play a significant role in their performance [14–17]. Later studies that used Brahman as the Bos...
*indicus* breed and Hereford or Angus as the *Bos taurus* breed supported this hypothesis and documented differences between the reciprocal F₂ cows for reproductive traits, but with smaller datasets [18,19]. Boenig [18] observed that F₂ Brahman–Hereford cows from F₁ Hereford × Brahman sires outperformed those from F₁ Brahman × Hereford sires for calf crop born and calf crop weaned. The early work in Australia [14,15] that reported unexpected hybrid vigor loss in advanced generations utilized Brahman-sired F₁ females. Further investigation is required to determine if this is a novelty for Brahman or if these differences are present in other *Bos indicus* breeds. The objective of this study was to analyze differences in birth date, birth weight, and weaning weight among reciprocal F₂ Nellore–Angus calves relative to the reciprocal types of F₁ parents. An additional objective to investigate potential differences in calf sex ratios was added after the preliminary analyses began.

2. Materials and Methods

Calf performance and sex distribution traits were evaluated using data from the F₂ Nellore–Angus (cycle 2) herd of the McGregor Genomics Project at Texas A&M University/Texas A&M AgriLife McGregor Research Center. All animal work and data collection were conducted under approved institutional animal care and use protocols.

The McGregor Research Center is located at 31° north, −97° east. All animals in this project were born in the Research Center. Animals were housed year round on predominantly warm season, improved, perennial pastures with supplemental feeding typical during the winter months of November through February. Herds were managed for spring calving with typical breeding seasons occurring in May through July annually. All females in this project were exposed to multiple-sire groups of bulls that passed annual breeding soundness examinations for natural service mating. Calves had birth date and birth weight recorded within 24 h of birth. Calves were vaccinated for clostridial diseases at 2 to 4 months of age and typically weaned at approximately 7 months of age; however, in the harsh drought year of 2011, calves were weaned 2 months early. Approximately 1 month prior to weaning, calves were administered a bovine respiratory disease (BRD) vaccine. At calf weaning, calves were weighed and received booster clostridial and BRD vaccinations. At this time (or at preweaning), cows were pregnancy checked, weighed, and had a body condition score assigned. Cows were typically managed to maintain a body condition score of 5 to 6 (on a 1 to 9 scale).

There were 539 reciprocal crossbred F₂ Nellore–Angus calves born from 2010 to 2015. These included F₁ Nellore-sired (NA) and F₁ Angus-sired (AN) parental combinations of NA × NA (NANA), NA × AN (NAAN), AN × NA (ANNA), and AN × AN (ANAN). Of these 539, 301 were male and 238 were female. Analyzed traits included two focus areas: (1) calf performance traits of Julian birth date, birth weight, and weaning weight among these F₂ crosses, and (2) percent male calves at birth and weaning. Sire and dam were included as random effects for all analyses. Significance levels considered were \( p \leq 0.10 \) for potential trends and \( p \leq 0.05 \) for difference comparisons.

Julian birth date, calf birth weight, and weaning weight were evaluated using mixed models (PROC MIXED in SAS 9.4). Independent fixed effect variables included sire type (NA vs. AN), dam type (NA vs. AN), calf sex, birth year, and cow age group (3 to 4, 5 to 9, 10 to 12, and 13 to 18 years); possible interactions involving sire type, dam type, and calf sex were investigated. The regression on Julian birth date was included in the birth weight model in the preliminary analyses, but was removed from the final model due to potential genetic differences that were possibly independent of birth weight. The regression on calf age at weaning was included in the weaning weight models. Dam age was confounded with birth year and was removed from the weight trait models.

Percentages of male calves (of total number) at birth and at weaning were evaluated by following a binomial distribution PROC GLIMMIX (SAS 9.4), and potential deviations from the binomial expectations for sex ratio were evaluated relative to \( \alpha = 0.05 \). The statistical models for sex frequencies included independent variables of sire type (NA vs. AN), dam
type (NA vs. AN), interactions between sire type and dam type, and cow age group. Only two cow age group categories were evaluated in the F<sub>2</sub> calves (3 to 4 years vs. 5 to 18 years). The preliminary analyses used four cow age groups (3 to 4, 5 to 9, 10 to 12, and 13 to 18 years) to create a more even distribution of cows per each group. However, the initial analyses showed cows aged 5 years and older had calf sex ratios within a reasonable range of expectation (49.6% male to 54.3% male at birth and weaning, respectively) and were, therefore, combined into one group (5 to 18 years).

3. Results

A general summary of calf performance traits of the F<sub>2</sub> reciprocal calves is shown in Table 1, and the summary of significance levels from the statistical analyses of calf traits is provided in Table 2. Table 3 provides means for calf performance trait effects. The calf trait results are provided individually by section below.

Table 1. Summary statistics for F<sub>2</sub> calf traits.

| Variable                  | n   | Mean | Standard Deviation | Minimum | Maximum |
|---------------------------|-----|------|--------------------|---------|---------|
| Julian birth date, d      | 496 | 71.9 | 16.0               | 17.0    | 137.0   |
| Birth weight, kg          | 495 | 35.5 | 7.15               | 19.0    | 59.0    |
| Weaning weight, kg        | 489 | 224.4| 35.22              | 107.0   | 303.9   |
| Weaning age, d            | 490 | 204  | 27.3               | 86.0    | 275.0   |

Table 2. Summary of significance levels from mixed model analyses of F<sub>2</sub> calf traits.

| Effects                              | Julian Birth Date | Birth Weight | Weaning Weight |
|--------------------------------------|-------------------|--------------|----------------|
| Sire type                            | 0.134             | 0.002        | 0.281          |
| Dam type                             | 0.010             | 0.048        | 0.708          |
| Sex                                  | 0.914             | <0.001       | <0.001         |
| Birth year                           | <0.001            | <0.001       | <0.001         |
| Sire type × Dam type                  | 0.305             | 0.452        | 0.038          |
| Sire type × Dam type × Sex            | 0.544             | 0.106        | 0.268          |
| Cow age group                        | 0.002             | –            | –              |
| Weaning age                          | –                 | –            | <0.001         |

Table 3. Least squares means for Julian birth date, birth weight, and weaning weight of F<sub>2</sub> calves.

| Effect                  | n  | Mean | SE  | n  | Mean | SE  | n  | Mean | SE  |
|-------------------------|----|------|-----|----|------|-----|----|------|-----|
| Julian Birth Date (d)   |    |      |     |    |      |     |    |      |     |
| F<sub>1</sub> Angus × Nellore | 217 | 68.7 | 2.31 | 257 | 32.9 | 0.86 | 214 | 218.6 | 3.08 |
| F<sub>1</sub> Nellore × Angus | 277 | 72.7 | 2.39 | 299 | 36.4 | 0.86 | 273 | 222.9 | 3.07 |
| Birth year (Calving dates) |    |      |     |    |      |     |    |      |     |
| 2010 (Jan 29–Mar 20)    | 87  | 64.0 | 2.39 | 87  | 32.8 | 0.90 | 87  | 224.7 | 3.44 |
| 2011 (Feb 11–May 4)     | 109 | 63.0 | 2.11 | 109 | 33.6 | 0.81 | 108 | 216.4 | 3.89 |
| 2012 (Feb 25–May 18)    | 100 | 81.0 | 2.16 | 99  | 37.1 | 0.84 | 100 | 225.4 | 2.92 |
| 2013 (Jan 25–Mar 17)    | 91  | 72.9 | 2.32 | 91  | 36.1 | 0.89 | 91  | 228.5 | 3.11 |
| 2014 (Feb 27–May 2)     | 88  | 82.4 | 2.34 | 88  | 35.7 | 0.90 | 82  | 218.1 | 3.29 |
| 2015 (Jan 18–Mar 13)    | 19  | 59.1 | 3.70 | 19  | 32.5 | 1.61 | 19  | 211.1 | 5.77 |
Table 3. Cont.

| Effect | n  | Mean  | SE  | n  | Mean  | SE  | n  | Mean  | SE  |
|--------|----|-------|-----|----|-------|-----|----|-------|-----|
|        | Julian Birth Date (d) | Birth Weight (kg) | Weaning Weight (kg) |
| Sire type × Dam type | | | | | | | | |
| AN × AN | 70 | 64.6  | 2.88 | 70 | 31.9  | 1.07 | 67 | 215.9 | 3.85 |
| AN × NA | 147 | 71.5  | 2.41 | 146 | 33.8  | 0.92 | 147 | 221.2 | 3.27 |
| NA × AN | 110 | 70.6  | 2.86 | 110 | 35.9  | 1.03 | 107 | 224.5 | 3.68 |
| NA × NA | 167 | 74.8  | 2.48 | 167 | 36.9  | 0.91 | 166 | 221.2 | 3.25 |
| Cow age group, yr | | | | | | | | |
| 3 to 4 | 127 | 75.8  | a  | 2.11 | – | – | – | – | – |
| 5 to 9 | 156 | 69.3  | b  | 2.06 | – | – | – | – | – |
| 10 to 12 | 71 | 69.2  | b  | 2.76 | – | – | – | – | – |
| 13 to 18 | 140 | 67.3  | b  | 2.36 | – | – | – | – | – |

1 AN = F₁ Angus × Nellore, NA = F₁ Nellore × Angus. 

\(^{a,b}\) LS means within effects (on different rows) that do not share a superscript differ \((p < 0.05)\).

3.1. Calf Performance Traits

3.1.1. Julian Birth Date

Dam type (NA vs. AN), birth year, and cow age group accounted for differences in Julian birth date \((p < 0.05)\). The F₂ calves out of AN dams were born approximately 6 days earlier than those from NA dams (68 ± 2.3 days vs. 73 ± 1.9 days). Additionally, calves born in 2015 had the earliest Julian birth date mean at 59 days while those born the year prior, 2014, had the latest at 82 days. Calves out of older cows displayed a trend of having earlier Julian birth dates than those out of younger cows (67 ± 2.4 days for cows 13–18 years old vs. 75 ± 2.1 days for cows aged 3–4 years).

3.1.2. Birth Weight

Sire type, dam type, calf sex, and birth year all affected \((p < 0.005)\) birth weight in these reciprocal F₂ calves. Calves that had a Bos indicus-sired sire or dam (NA) were heavier than those with Bos taurus-sired sires or dams (AN). The calves from NA sires weighed 3.5 kg more than those from AN sires. Calves out of NA dams were 2.4 kg heavier (35.8 ± 0.70 kg vs. 33.4 ± 0.73 kg) than those out of AN dams.

Male calves in this study were heavier than female calves at birth (35.8 kg vs. 33.4 kg, respectively), and this difference was similar to what has been reported in most other purebred and composite populations. However, among reciprocal breed types, there appeared to be a different trend occurring in the NA-sired F₂ calves. Bull and heifer calves had numerically similar birth weights with NAAN bull calves weighing only 1.1 kg more than NAAN heifer calves (36.5 ± 1.10 kg vs. 35.3 ± 1.32 kg) and NANA bull calves weighing 0.8 kg more than NANA heifer calves (37.3 ± 0.99 kg vs. 36.5 ± 1.08 kg). Male calves with AN sires had numerically larger birth weights averaging 3.9 kg heavier than females (34.8 kg vs. 30.9 kg). Birth weights fluctuated through the study years with the heaviest calves born in 2012 (37.1 ± 0.84 kg) and the lightest born in 2015 (32.5 ± 1.61 kg). Figure 1 shows the means for the three-way interaction of sire type × dam type × sex \((p = 0.106)\), but these means were not formally compared due to this significance level.
There were only two cow age group categories evaluated (cows aged 3 to 4 years vs. cows aged 5 to 18 years) because the preliminary analyses showed cows aged 5 years and older had calf sex ratios that were within a reasonable range of expectation. Only sire type caused different sex ratios between F₂ calves for percent males at birth and weaning (p < 0.05).

Table 4 provides a summary of significance levels for the percent of the F₂ calf crop that were males at birth and weaning. Analyses included calves born from 2010 to 2015. There were only two cow age group categories evaluated (cows aged 3 to 4 years vs. cows aged 5 to 18 years) because the preliminary analyses showed cows aged 5 years and older had calf sex ratios that were within a reasonable range of expectation. Only sire type caused different sex ratios between F₂ calves for percent males at birth and weaning (p < 0.05).

Table 4. Significance levels from analyses of percent male calves at birth and weaning among F₂ calves.

| Effect                  | Percent Male at Birth | Percent Male at Weaning |
|-------------------------|-----------------------|-------------------------|
| Sire type               | 0.036                 | 0.026                   |
| Dam type                | 0.937                 | 0.820                   |
| Sire type × Dam type    | 0.394                 | 0.368                   |
| Cow age group           | 0.058                 | 0.057                   |

Figure 1. Birth weight by type of F₂ cross and calf sex. The first and second letters indicate the type of F₁ sire (AN or NA), and the third and fourth letters indicate the type of F₁ dam (AN or NA) resulting in four possible sire–dam combinations of ANAN, ANNA, NAAN, and NANA.

3.1.3. Weaning Weight

Calf sex, birth year, weaning age, and the interaction between sire type and dam type accounted for the weaning weight differences in these F₂ calves (p < 0.005). As calf age increased, weaning weight increased by 0.83 ± 0.067 kg per day.

Male calves were 17.2 kg heavier at weaning than female calves (229.3 ± 2.52 kg vs. 212.1 ± 2.61 kg). Calves weaned in 2013 ranked the heaviest across all years at 228.5 kg, and those born in 2015 were the lightest at 211.2 kg. Calves out of NA-sired dams, ANNA and NANA, had the same weaning weight at 224.5 ± 3.68 kg. Calves out of NA-sired dams, ANNA and NANA, had the same weaning weight at 224.5 ± 3.68 kg. Calves out of NA-sired dams, ANNA and NANA, had the same weaning weight at 224.5 ± 3.68 kg. Calves out of NA-sired dams, ANNA and NANA, had the same weaning weight at 224.5 ± 3.68 kg. Calves out of NA-sired dams, ANNA and NANA, had the same weaning weight at 224.5 ± 3.68 kg.

Table 5 provides means for each effect for these two variables as well as significance results of frequencies that deviate from binomial expectations. The F₁ AN bulls’ calf crop displayed the expected 1:1 male to female sex ratio with a mean of 49.9% males at birth and 49.3% males at weaning while F₁ NA bulls had substantially more males at birth and at weaning with 66.6% and 66.5%, respectively. Additionally, these NA-sired calves deviated significantly from the expected sex ratio. Calves out of AN dams, as well as those that...
were NAAN and NANA, also differed from the typical 50% with average frequencies of 58.2%, 64.5%, and 58.3% male, respectively, at birth and weaning ($p < 0.05$). Cow age group displayed a trend for percent males at birth and at weaning ($p = 0.058$ and $p = 0.057$, respectively). The younger cow group had 11.4% more males at birth and 11.6% more males at weaning (64.1% ± 5.21% vs. 52.7% ± 4.50%, and 63.8% ± 5.11% vs. 52.2% ± 4.37%), and significantly deviated from the expected sex ratio.

Table 5. Least squares means for percent males at birth and weaning among $F_2$ calves.

| Effect                          | n Males | Birth Records | n Total | Mean  | SE  | Weaning Records | n Total | Mean  | SE  |
|--------------------------------|---------|---------------|---------|-------|-----|----------------|---------|-------|-----|
| Sire type                      |         | n Males       | n Total | Mean  | SE  | n Males       | n Total | Mean  | SE  |
| $F_1$ Angus × Nellore          | 105     | 219           | 49.9%   | 5.62% | 103 | 216           | 49.3%   | 5.39% |
| $F_1$ Nellore × Angus          | 168     | 277           | 66.6%   | 5.32% | 166 | 273           | 66.5%   | 5.13% |
| Dam type                       |         | n Males       | n Total | Mean  | SE  | n Males       | n Total | Mean  | SE  |
| $F_1$ Angus × Nellore          | 105     | 180           | 58.3%   | 5.03% | 101 | 174           | 57.5%   | 4.97% |
| $F_1$ Nellore × Angus          | 168     | 316           | 58.7%   | 4.56% | 168 | 315           | 58.7%   | 4.41% |
| Sire type × Dam type           |         | n Males       | n Total | Mean  | SE  | n Males       | n Total | Mean  | SE  |
| AN × AN                        | 34      | 70            | 47.5%   | 7.47% | 32  | 67            | 46.3%   | 7.38% |
| AN × NA                        | 71      | 149           | 52.3%   | 6.27% | 71  | 149           | 52.2%   | 6.05% |
| NA × AN                        | 71      | 110           | 68.3%   | 6.34% | 69  | 107           | 67.9%   | 6.24% |
| NA × NA                        | 97      | 167           | 64.9%   | 5.91% | 97  | 166           | 65.0%   | 5.71% |
| Cow age group (yr)             |         | n Males       | n Total | Mean  | SE  | n Males       | n Total | Mean  | SE  |
| 3 to 4                         | 80      | 128           | 64.1%   | 5.21% | 79  | 127           | 63.8%   | 5.11% |
| 5 to 18                        | 193     | 368           | 52.7%   | 4.50% | 190 | 362           | 52.2%   | 4.37% |

$^1$ AN = $F_1$ Angus × Nellore, NA = $F_1$ Nellore × Angus. $^a,b$ LS means within effects (rows) that do not share a superscript differ ($p < 0.05$). $^s$ Unadjusted frequency deviated from binomial expectations ($p \leq 0.05$).

4. Discussion

4.1. Calf Performance Traits

4.1.1. Julian Birth Date

Dam type was the only influential breed type effect for Julian birth date ($p < 0.05$) with calves out of $Bos$ taurus-sired dams, AN, being born earlier in the calving season than those out of $Bos$ indicus-sired dams, NA, ($68 \pm 2.3$ days vs. $73 \pm 1.9$ days). While not significant ($p = 0.134$), sire type of the $F_2$ calves had a similar pattern. Calves sired by AN bulls were born approximately 5 days earlier than those sired by NA bulls ($69 \pm 2.3$ days vs. $73 \pm 2.4$ days).

Not many reports of Julian birth dates among reciprocal $Bos$ indicus–$Bos$ taurus crosses were found in the scientific literature. Franke et al. [20] found a related pattern when evaluating birth and weaning traits in two-, three-, and four-breed rotation crossbred cattle. For stabilized two-breed rotations, calves with $Bos$ taurus sires were born sooner than those with $Bos$ indicus sires. Angus (A)- and Hereford (H)-sired calves were born 4 days and 6 days earlier, respectively, than those from Brahman (B) sires ($50$ days for both $A \times$ one-third $A$ and two-thirds $B$ and $H \times$ one-third $H$ and two-thirds $B$ vs. $54$ days for $B \times$ one-third $B$ and two-thirds $A$ and $56 \pm 2$ days for $B \times$ one-third $B$ and two-thirds $H$). Franke et al. [20] also stated that $Bos$ indicus (Brahman) breed effects in the calf and in the dam increased Julian birth date compared to British breed influence.

Although not the same trait, it was likely that some similarities existed between Julian birth date and gestation length in these types of crosses. Baker et al. [21] and Thallman et al. [22] found increased gestation lengths in $Bos$ indicus-sired $F_1$ calves vs. their reciprocal $Bos$ taurus-sired $F_1$ contemporaries. Among reciprocal backcrosses, Amen et al. [12] reported 2–3-day longer gestation lengths when $F_1$ parents (sires and dams) were $Bos$ indicus-sired vs. $Bos$ taurus-sired and bred to pure $Bos$ indicus (Brahman) or pure $Bos$ taurus (Angus). In the present study, there was no way to resolve how much of the differences in Julian birth dates were due to differences in cow conception dates vs. differences in gestation lengths.
Year effects ($p < 0.05$) seen in these $F_2$ calves were possibly due at least in part to differences in annual turn out time of the bulls. Additionally, the differences seen among dam age ($p < 0.05$) were possibly a product of culling practices; for instance, cows that calve later in the calving season have less subsequent time to breed back and may be more likely to be culled over time. Cows in this study remained in the herd until they failed to wean a calf twice or had an obvious problem (i.e., health issue) up to 12 years of age. Afterwards, they were culled for any failure to wean a calf.

4.1.2. Birth Weight

Among $F_2$ calves, those that had a $Bos$ indicus-sired dam (NA) were heavier than those with $Bos$ taurus-sired dams (AN) ($p < 0.05$). These results were consistent with previous research on $F_2$ crosses involving Brahman (B) and Hereford (H), where Boenig [18] found calves out of BH cows weighed 1.8 kg more at birth (36.5 kg) than those out of HB cows (34.7 kg). In evaluating backcross embryo transfer calves, Amen et al. [12] observed that calves out of Angus cows that had $F_1$ AB sires were 2.7 kg heavier at birth than those with $F_1$ BA sires (39.4 kg vs. 36.8 kg), but no differences were seen in calves from AB vs. BA $F_1$ females.

Results in these $F_2$ calves seemed to follow a related pattern to what has been seen in $F_1$ Brahman–Bos indicus crosses, but with a less severe difference between birth weights. For example, Roberson et al. [8] found that for Brahman–Hereford crossbred calves, in general, birth weight increased with the greater amount of Brahman in the sire compared to Brahman in the dam. First generation calves with Brahman sires were 7 kg heavier than those with Hereford sires (37.4 kg vs. 30.4 kg). Calves that had Hereford sires and $F_1$ dams or $F_1$ sires and $F_1$ dams had comparable birth weights of 32.1 kg and 31.9 kg, respectively. Additionally, in a more recent study, Dillon et al. [11] found that $F_1$ Brahman × Simmental (S) calves were approximately 9.4 kg heavier than $F_1$ Simmental × Brahman calves (41.1 vs. 31.7, respectively).

The $F_2$ calves with $Bos$ indicus-sired sires did not have large birth weight differences between sexes such as those seen in $F_1$ Brahman–Bos indicus crosses. For example, in birth weights of reciprocal Brahman–Angus crossbred calves, Brown et al. [9] reported Brahman-sired bull calves were 13.7 kg heavier than Angus-sired bull calves, and Brahman-sired heifers were 7.4 kg heavier than Angus-sired heifers. Other studies have observed similar patterns and values [10,22].

Birth weights fluctuating throughout the study years were possibly a result of seasonal conditions affecting nutrient availability differently throughout the years and/or differences among individual sires. Conception date, gestational length, and family differences may have all played a role in birth weight variation across the years.

4.1.3. Weaning Weight

Increased weight gain with calf age seen in this study was likely the typical result of older calves having more time to gain weight. The lightest weaning weight year corresponded with the lightest birth weight year while the years with the heaviest weaning weights and heaviest birth weights were different. However, 2012, the heaviest birth weight year, had the second heaviest weaning weight at 225.4 kg, only a 3.1 kg difference to the heaviest weaning weight year in 2013. The relatively small reciprocal differences between breed types in weaning weight seen in this study followed a similar trend to work by Boenig [18], where calves with $F_1$ Brahman × Hereford cows were only 6.0 kg heavier than those out of $F_1$ Hereford × Brahman cows (234.9 kg).

4.2. Sex Frequencies among $F_2$ Calves

It was unclear whether the differences in calf sex ratio observed in these data followed any biological or environmental pattern or influence. We were surprised to see the large percentage of males from NA sires (66.6%) and from 3–4-year-old dams (64.1%). Fisher [23] showed that natural selection favored parents that equally invested their energy
into making both sexes. However, Trivers and Willard [24] suggested that under certain circumstances, parental “condition” could create a deviation in this ratio. Research has also indicated that effects such as maternal diet, parental hormone levels, and parental age may impact sex ratios in several mammalian species [25–28], but we did not find reports of similar results in cattle.

While the trend of younger cows in this study having a higher frequency of male offspring was not identified in the scientific literature for cattle, it was similar to what has been reported in horses [25]. Santos et al. [25] found that younger parents had a higher proportion of male offspring; stallion age was influential and followed a similar trend, but the effects were less severe than with mares. Sex ratios for males:females from mares ≤10 years were 1.2 (20% more males), but were 0.64 to 0.78 for males:females from mares ≥15 years [25]. Somewhat related patterns have also been reported in sheep. Kent [26] found a positive correlation between flock age and sex ratio in Suffolk cross ewes where percentage male lambs increased from 49.6% in 2-year-old ewes to 54.3% in 4-year-old ewes, and then began to decrease after 4.8 years of age. Kent [26] theorized that these results might have been caused due to dams at intermediate ages and peak maternal conditions preferentially producing more males to propagate their genes.

Variation in sex ratios from sires has been reported in cattle. Powell et al. [29] reported, in dairy bulls with at least 80 progeny each, that gross ratios for percentage male progeny ranged from 38.7 to 64.4%. Ejaculates from Holstein bulls have varied from 24 to 84% for percentages of Y-chromosome-bearing sperm cells, and the percentage of male calves from these bulls’ ejaculates ranged from 16.1 to 72.3% [30]. The percentage of Y-chromosome-bearing sperm cells has also varied with bull collection frequency [31]. Baublits et al. [32] evaluated five purebred beef herds and saw no differences in sex ratio across breeds, but stated that some sires consistently produced skewed ratios for calf sex. Recently, sire differences have been found for placentation and embryo loss [33] which historically have been thought of as traits of females. There is a need to evaluate the age of sires from cattle studies for these effects to complement age of dam information from other species. It is likely that several factors may contribute to sex ratio variation which have previously been attributed to “random” variation from undocumented sources.

5. Conclusions

The objective of this study was to investigate reciprocal differences in Bos indicus–Bos taurus F₂ crossbred calves, as previous research has indicated that the parental cross to make F₂ cows likely plays a significant role in their performance and the performance of their offspring [14–19]. The reciprocal type of F₁ dam influenced calf Julian birth date, the F₁ dam type and F₁ sire type influenced birth weight, and the interaction between sire type and dam type influenced weaning weight. The type of F₁ sire also influenced weaning weight. The type of F₁ sire also influenced calf sex ratio.

Patterns of increased birth weight in these F₂ calves appeared related to results in F₁ and backcross Bos indicus–Bos taurus calves with heavier weight when Bos indicus influence was inherited through the sire rather than the dam line of descent. However, no clearly related pattern for exaggerated sex differences in these F₂ calves was observed relative to what has been reported among F₁ crosses. Results regarding differences in calf sex ratios from sire type and age of dam were surprising, and we did not have a hypothesis for why this occurred. We recommend investigators working with new composite populations and composite breeds that allow the creation of new “first generation” animals record how the foundational Bos indicus–Bos taurus F₁ crosses are generated (sire × dam) and explore if similar differences can be modeled in these and related performance traits.

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Institutional Review Board Statement: This study was conducted according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching, 3rd ed. (2010) of the Federation of Animal Science Societies. All animal procedures were reviewed and approved by the Texas A&M University Institutional Animal Care and Use Committee under protocol numbers 2008-234 and 2012-103.

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