

Article

Health and Growth Performance During the Pre-Weaning Phase of Angus × Holstein Crossbred and Holstein Calves Managed Under the Same Conditions

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Abstract: There are few studies on how dairy × beef crossbred calves perform during the pre-weaning phase compared to dairy calves. This observational study evaluated birth weight, average daily gain (ADG), and disease occurrence in Angus × Holstein (Ang × Hol) crossbred and Holstein calves reared under the same conditions on a commercial dairy farm. Retrospective data from 379 calves (290 Holstein females; 89 Ang × Hol crossbreds: 46 males, 43 females) born between January 2022 and August 2023 were analyzed. Variables included dam parity, calving type, birth weight, colostrum Brix levels, serum total protein (STP), mortality, disease occurrence, ADG, and weaning weight. Statistical analysis used linear and logistic regression models. Ang × Hol male calves had higher odds of assisted calving. Male and female Ang × Hol calves had greater birth weights than Holstein calves, with males being the heaviest. No differences in STP were observed. Ang × Hol calves (both sexes) showed higher ADG than Holsteins but did not differ from each other. Holstein calves had higher odds of diarrhea (OR: 2.95, 95% CI: 1.63–5.35), while Bovine Respiratory Disease (BRD) incidence was similar across groups. Overall, Ang × Hol crossbred calves demonstrated superior growth and lower diarrhea risk under the same management conditions.



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Keywords: beef-on-dairy; bovine respiratory disease; calf management; diarrhea

1. Introduction

The term “beef-on-dairy” refers to a breeding strategy that involves the use of beef cattle semen in dairy cows, aiming to produce offspring for meat production from dairy herds [1]. This increasingly popular approach is viewed as a potential solution to mitigate the issue of surplus male dairy calves [2]. Additionally, improvements in reproductive performance among dairy herds—coupled with a slowdown in herd expansion in many developed countries—have led to a reduced demand for dairy heifers. As a result, the need to maintain cash flow through the sale of surplus calves for meat production, along with the often negligible market value of male dairy calves, supports the adoption of this strategy on dairy farms [1,3]. However, few studies have compared the performance and health of crossbred (beef-on-dairy) and purebred dairy calves during the pre-weaning phase.

A study that evaluated 40 dairy farms that adopted the beef-on-dairy strategy found that 12.5% of these farms do not perform umbilical cord treatment on crossbred calves after birth, 50% do not vaccinate crossbred calves for diarrhea and BRD, 47.5% do not assess

colostrum quality, and 50% do not provide a second colostrum feeding [4]. These data demonstrate that, similar to Holstein male calves [5,6], crossbred calves do not receive the same standard of care as female Holstein calves, highlighting serious welfare and management issues. Due to these differences in care and management, comparing the development and disease occurrence between dairy and crossbred calves during the pre-weaning phase is challenging. To date, few studies that provide crossbred calves the growth and health targets established for raising dairy calves [7] have been conducted.

Some studies have evaluated dystocia [8,9], birth weight [9], dry matter intake [10], weight gain [10–12], feed efficiency [10], carcass yield [13], loin area [14], and prevalence of liver abscess [15] when comparing dairy breeds with crossbred cattle. However, limited research has been conducted to compare the performance of crossbred calves during the pre-weaning phase. In addition, pre-weaning performance has been found to directly impact the success of subsequent stages in the animal's life [16–18].

The objective of this study was to assess the performance and health of Holstein $\times$ Angus crossbred and purebred Holstein calves on birth characteristics, colostrum management, serum total protein (STP), mortality, disease prevalence, and ADG (Average daily gain); subjected to the same rearing system during the pre-weaning phase. We hypothesized that Holstein $\times$ Angus crossbred calves would have increased growth and reduced disease occurrence compared to Holstein dairy calves.

2. Materials and Methods

This retrospective observational study used data from a large high producing Holstein dairy farm in Palmeira, Paraná, Brazil. Retrospective data from January 2022 to August 2023 were collected from the DelPro[®] system and entered in Excel spreadsheets. The study was approved by the Animal Ethics Committee of Pontifical Catholic University of Paraná under protocol number 3206250723 (ID 000048). A priori sample size calculation was performed using the “pwd” function from Rstudio (version 4.3.3, <https://www.r-project.org/> (accessed on 7 Jan 2024)) based on detectable difference of 0.150 kg/day in ADG [19,20]. For that, using 80% power, a significance level set at $p < 0.05$, and a standard deviation of 0.250 kg/day, 44 calves would be required in each group. To detect a 20% difference in diarrhea occurrence (Crossbred: ~55% [21]; Holstein: 75% [historical farm records]) with a ratio of 5 Holstein calves to 1 crossbred calf, 54 crossbred calves and 270 Holstein calves would be required in each group, with 80% power and a significance level set at $p < 0.05$. Thus, a total of 379 calves were included (Angus $\times$ Holstein crossbred: $n = 89$ [46 males and 43 females] and Holstein: $n = 290$ females, contemporaneous). Data collected included date of birth, sex, genetic compositions, calving type (categorized from 0 to 3; 0 = normal/no assistance, 1 = small manual effort/slight assistance, 2 = obstetric ropes, light mechanical traction/moderate assistance, and 3 = assistance by two people, or the use of a calf puller/difficult assistance required), birth weight, colostrum quality (Brix), serum total protein (STP), date of disease occurrence, disease incidence until weaning, age at weaning, and weaning weight. To make consistent comparisons between Angus $\times$ Holstein (Ang $\times$ Hol) crossbred and Holstein calves, only Holstein calves born to multiparous cows were included in the study, since all dams of the Ang $\times$ Hol crossbred calves were multiparous.

As per standard management, all calves were separated from their dams within 2 h of birth and moved to individual calf pens (1.20 $\times$ 2.50 m). Umbilical cord treatment was performed on all animals using a 10% iodine solution once daily for 3 days. Colostrum volume was offered at 10% of the calf's body weight, sourced either from fresh colostrum or colostrum bank (refrigerated/frozen), with a set minimum of 22 Brix degrees administered via esophageal tube within the first 2 h of life, and 5% of body weight in colostrum in a

second feeding (6 to 8 h after the first feeding), provided via bottle. Blood samples were collected 24 to 48 h after the first colostrum feeding to assess STP (serum total protein) through jugular vein puncture. Serum was analyzed using a total protein refractometer (Sper Scientific, Scottsdale, AZ, USA). Transfer of passive immunity was evaluated using total protein values and classified according to Godden et al. [22] as follows: poor: <5.1 g/dL, fair: 5.1–5.7 g/dL, good: 5.8–6.1 g/dL, and excellent: ≥ 6.2 g/dL.

Calves received transition milk until their fourth day of life, followed by pasteurized waste milk (pool of milk from treated cows, transition milk, and mastitis milk) combined with milk replacer ([DM: 22% CP, 17% EE, 44% Lactose] Nutrifeed, Voorthuizen, The Netherlands) to achieve 14% total solids. All calves were bottle-fed, divided into 2 feedings per day at 08:00 and 16:00. Feeding volume varied with age intervals: 1 to 4 days received 4 L/d of transition milk; 5 to 14 days received 6 L/d; 15 to 49 days received 8 L/d; 50 to 65 days received 6 L/d; 66 to 69 days received 4 L/d; and from 70 days until weaning received 2 L/d. Water and concentrate (86% DM, 24% CP, 2.3% EE, 5.2% CF, FDN 15%, TDN 70%, 4% Mineral matter, with coccidiostatic added [40 mg/kg sodium monensin]) were provided ad libitum from day 1. Starting day 51, TMR was provided (% DM: 19.39% ground corn, 9.91% soybean meal, 11.01% barley, 1.09% mineral supplement, 25.55% oats, 33.04% corn silage). All calves were completely weaned at 77 ± 2 days of age.

Calves were housed in individual pens of 3 m² (1.20 × 2.50 m) until 50 d of age, then paired into double pens. After removing the partitions (pairing), paired animals were housed in pens of 2.40 × 2.50 m, totaling 6 m². The calves were paired randomly. Pens had concrete flooring covered with wheat straw and sawdust (~20 cm). Each calf had one feed bucket and one water bucket. The barn had natural daylight and ventilation.

The health assessments were conducted daily by two trained staff members under the supervision of a veterinarian, in accordance with the fecal scoring and Calf Respiratory Health Score as outlined by McGuirk [23]. Calves positive for diarrhea and BRD were treated according to farm veterinary protocols. Treatment criteria were based on an adapted Wisconsin Health Score [23], where calves showing signs of respiratory disease (ear position change, cough, ocular discharge, nasal discharge) plus fever (>39.4 °C) were treated with meloxicam (Metacam, Boehringer Ingelheim Vetmedica Inc., Duluth, MN, USA) plus florfenicol (Nuflor, Merk, Darmstadt, Germany). Calves with fecal scores ≥ 2 were treated with electrolyte replacement, oral probiotic paste (Lactobac bovis, Organnact, Curitiba, Brazil), and flunixinina meglumina (Flumax, JA Saúde Animal, Patrocínio Paulista, Brazil). For diarrhea with fever, treatment included electrolyte replacement, oral probiotic paste (Lactobac bovis, Organnact, Curitiba, Brazil), flunixinina meglumina (Flumax, JA Saúde Animal, Patrocínio Paulista, Brazil), and Trimethoprim/sulfadoxine combination (Borgal, Merk, Darmstadt, Germany). The pharmacological choices and dosages used for each disease and clinical presentation were similar for all groups. A new case of diarrhea was considered when the event occurred more than 7 d after the first case of diarrhea [23,24]. A new case of BRD was considered when a positive diagnosis occurred more than 14 d after the first case of BRD [25].

Weight measurements were taken at birth using a hoof weight tape (Calfscale BW Tape; Nasco, Fort Atkinson, USA) [26,27] and at weaning using a chest girth weighing tape for cattle (APCBRH, Curitiba, Brazil) [28]. The ADG was calculated based on the weaning weight minus the birth weight, divided by the total number of days in the suckling period.

Statistical Analyses

The statistical analyses were performed in R [29] via RStudio [30], using linear models and logistic regression models to evaluate the relationships among groups with various dependent variables: birth weight, colostrum quality (in Brix terms), STP, calving type,

ADG, weaning weight, diarrhea occurrence, number of cases of diarrhea, BRD occurrence, number of cases of BRD, age at first BRD case, and age at first diarrhea case. Initial models included all potential measured confounders (e.g., Birth weight, dam parity) and were reduced through manual backwards elimination. However, the variables sex and genetic composition were retained in the statistical model, regardless of whether they were significant or not.

To enhance the analysis, the categorical variable calving type was transformed into binary format representing calving with assistance (yes/no) due to the low frequency of calves with assisted calving (2 and 3 categories). The variables for diarrhea and BRD were converted into binary format, with 'Yes' indicating animals that had the condition and 'No' indicating those that did not have it. When necessary, confounding factors were included as covariates based on a causal diagram, and intervening variables were added to better understand any remaining explanatory effects related to genetic compositions. For instance, STP was included as a covariate to assess the occurrence of BRD by groups. The results will be analyzed and reported by genetic compositions (Holstein females and Ang $\times$ Hol crossbred calves) and by group (Holstein females, Ang $\times$ Hol crossbred males, and Ang $\times$ Hol crossbred females). Interactions were not considered.

Linear models were employed to analyze associations of calf genetic compositions and group on the following variables: colostrum Brix, colostrum type, STP, birth weight, ADG, age at weaning, age at first BRD case, age at first diarrhea case, and effect of diarrhea on ADG. Furthermore, the effect of BRD on ADG and the effect of STP on ADG by group were also assessed. From the results of the linear models, we report the means and standard errors of the predictors, along with the associated p -values.

To analyze the count data—the number of BRD and diarrhea cases—Poisson, negative binomial, and linear regression models were fitted. The Lowest Akaike Information Criterion (AIC) was then used to assess model fit. For interpretation purposes, the results of the negative binomial and Poisson regression models were transformed into relative risk estimates. For the analysis of diarrhea case counts, the linear regression model demonstrated the best fit based on the lowest AIC and included the following fixed effects: breed composition and sex, STP, and birth weight. In contrast, for the analysis of BRD case counts, the negative binomial regression model yielded the lowest AIC and was fitted using the same set of fixed effects.

Logistic regression models were used to evaluate the probabilities of assisted calving and the occurrences of diarrhea and BRD. The models were fitted using the `glm()` function, with genetic composition, sex, calving type, birth weight, and STP as predictors. The results for the logistic regression models presented the odds ratios for the predictors, along with their corresponding 95% confidence intervals and p -values to indicate the statistical significance of the observed effects. Goodness-of-fit of the logistic regression models were assessed via Hosmer-Lemeshow goodness-of-fit test [31]. Linear regression model assumptions were assessed graphically. The assumptions were not violated in all models. The lowest p -value for these tests was 0.17, indicating that the models fit the observed data. A p -value less than 0.05 was considered statistically significant, while p -values between 0.05 and 0.10 were considered indicative of a tendency.

3. Results

3.1. Calving Type and Birth Weight

Holstein calves had 58% lower odds of being born through assisted calving compared to Ang $\times$ Hol crossbred calves (OR: 0.42; 95% CI: 0.20–0.86; $p = 0.01$). Furthermore, the groups were significantly associated with the odds of assisted calving ($p = 0.02$). Specifically, Ang $\times$ Hol crossbred female and Holstein female calves did not differ significantly in their

odds of being born from assisted calving ($p = 0.34$). In contrast, Ang $\times$ Hol crossbred male calves had 3.49 times higher odds of requiring assisted calving compared to Holstein female calves (95% CI: 1.43–8.25; $p < 0.01$), while their odds were similar when compared to Ang $\times$ Hol crossbred female calves (95% CI: 0.73–7.14; $p = 0.16$).

In terms of birth weight, Ang $\times$ Hol crossbred calves were significantly heavier than Holstein calves (crossbred: 40.4 ± 0.40 kg; Holstein: 36.9 ± 0.22 kg; $p < 0.01$). Notably, Ang $\times$ Hol crossbred male calves were 5.23 ± 0.58 kg heavier than Holstein calves (Table 1; $p < 0.01$) and 3.49 ± 0.78 kg heavier than Ang $\times$ Hol crossbred female calves (Table 1; $p < 0.01$). Additionally, differences in birth weight were observed between Holstein calves and Ang $\times$ Hol crossbred female calves (Table 1; $p = 0.01$).

Table 1. Birth weight, Brix of administered colostrum, STP, and ADG of Holstein female, Ang $\times$ Hol crossbred female, and male calves raised under the same management during the pre-weaning period.

Variable	Holstein Female	Crossbred ¹ Female	Crossbred ¹ Male
BW, kg	36.9 ± 0.21^a	38.6 ± 0.57^b	42.1 ± 0.54^c
Brix colostrum, %	24.9 ± 0.16	25.8 ± 0.44	25.2 ± 0.40
STP, mg/dL	6.33 ± 0.04	6.41 ± 0.13	6.47 ± 0.12
ADG, kg	1.31 ± 0.04^a	1.43 ± 0.04^b	1.47 ± 0.04^b

The data represent mean $\pm$ SEM. a, b, c. Different letters indicate statistical differences based on pairwise comparisons using the Tukey test. BW: Birth weight. STP: Serum total protein. ADG: Average daily gain.

¹ Crossbred: Ang $\times$ Hol crossbred.

3.2. Colostrum Management and Serum Total Protein (STP)

The Brix value of colostrum administered to calves did not differ significantly between genetic groups (Holstein: 24.6 ± 0.32 Brix; Ang $\times$ Hol crossbred: 25.5 ± 0.31 Brix; $p = 0.07$), nor was a significant overall group effect observed ($p = 0.19$; Table 1). Descriptively, a total of 12 calves (3.44% of Holstein, 0% of Ang $\times$ Hol crossbred female, and 2.17% of Ang $\times$ Hol crossbred male) received colostrum with $<22\%$ Brix.

We did not observe an effect of group on STP ($p = 0.52$; Table 1). Descriptively, Ang $\times$ Hol crossbred female calves had 73.33% of serum samples classified as excellent, while 16.67% were considered fair and 13.33% good; only 6.67% fell into the poor category. Holstein calves showed that 62.57% of samples were evaluated as excellent, with 13.94% fair, 22.75% good, and 4.04% poor, indicating overall good quality. In contrast, Ang $\times$ Hol crossbred male calves had 55% of samples classified as excellent, 10% fair, and 32.5% good, with no samples classified as poor.

3.3. Disease Occurrence

The descriptive data on the occurrence of diarrhea among the groups are presented in Figure 1a. Holstein calves showed a higher probability of occurrence of diarrhea compared to both male and female crossbred calves ($p < 0.01$, Figure 2). The probability of diarrhea occurrence showed that Holstein calves had 2.95 times higher odds of being diagnosed and treated for diarrhea compared to Ang $\times$ Hol crossbred calves (95% CI: 1.63–5.35; $p < 0.01$). Ang $\times$ Hol crossbred female calves showed a 69% reduction in the odds of developing diarrhea compared to Holstein calves (OR: 0.31; 95% CI: 0.15–0.67; $p < 0.01$; Table 2). While Ang $\times$ Hol crossbred male calves showed a 62% reduction in the odds of developing diarrhea compared to Holstein calves (OR: 0.38; 95% CI: 0.17–0.83; $p = 0.01$; Table 2). Ang $\times$ Hol crossbred female calves had similar odds of developing diarrhea compared to Ang $\times$ Hol crossbred male calves ($p = 0.76$). However, STP ($p = 0.14$) were not associated with the occurrence of diarrhea.

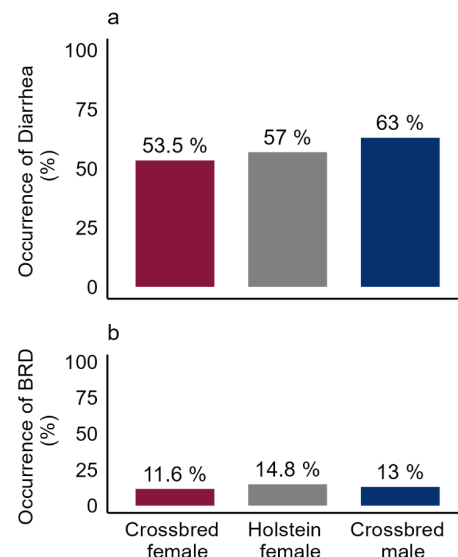


Figure 1. Descriptive data on disease occurrence of 290 Holstein and 89 Ang × Hol crossbred (46 males and 43 females) calves raised under the same management conditions during the pre-weaning phase: (a) Diarrhea occurrence by group. (b) Bovine Respiratory Disease (BRD) occurrence by group.

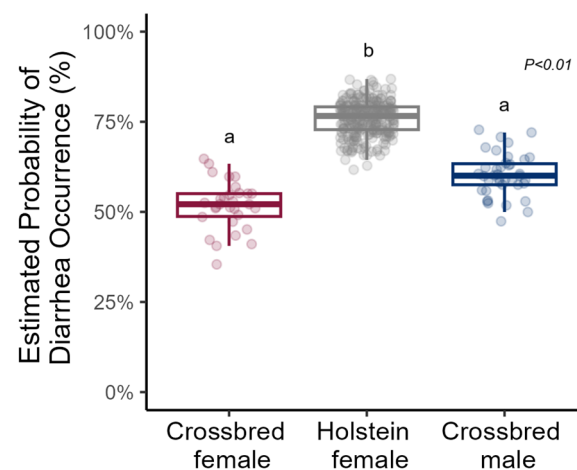


Figure 2. Estimated probability of diarrhea occurrence by group of 290 Holstein and 89 Ang × Hol crossbred calves raised under the same management conditions during the pre-weaning phase. ^{a,b} Different letters indicate statistical differences based on pairwise comparisons using the Tukey test. Error bars represent 95% CI.

The number of diarrhea cases were associated with genetic composition ($p < 0.01$). Holstein calves had a higher number of cases of diarrhea compared to Ang × Hol crossbred calves (Holstein: 1.01 ± 0.04 cases/calf; crossbred: 0.63 ± 0.07 cases/calf; <0.01). In terms of group, Holstein calves had a higher number of diarrhea cases compared to Ang × Hol crossbred female calves (Holstein female: 1.01 ± 0.04 cases/calf; Ang × Hol crossbred female: 0.58 ± 0.11 cases/calf; $p < 0.01$) and Ang × Hol crossbred male calves (Holstein female: 1.01 ± 0.04 cases/calf; crossbred male: 0.67 ± 0.10 cases/calf; $p = 0.01$). Female and male Ang × Hol crossbred calves did not differ in the number of diarrhea cases ($p = 0.80$). We did not identify an association between genetic compositions and the age at the first case of diarrhea (crossbred 16.8 ± 6.21 d; Holstein female: 10.5 ± 3.05 d; $p = 0.36$). The group of the calf also did not influence the age at the first case of diarrhea (Ang × Hol crossbred female: 15.4 ± 8.79 d; Ang × Hol crossbred male: 18.3 ± 8.70 d; Holstein female: 10.4 ± 3.06 d; $p = 0.64$).

Table 2. Models ¹ for the association among groups of calves, and Occurrence of Diarrhea and Occurrence of BRD, controlling for known confounders and experimental design.

Predictor	Est ³	Occurrence of Diarrhea				Est ³	Occurrence of BRD ²			
		OR	95% CI Lower	Upper	p-Value		OR	95% CI Lower	Upper	p-Value
Intercept	0.51	1.66	0.06	42.21	0.75	0.69	2.01	0.02	147.59	0.75
Group										
Holstein female	Referent	-	-	-	-	Referent	-	-	-	-
Crossbred ⁴ female	−1.14	0.31	0.15	0.67	<0.01	0.06	1.06	0.34	2.76	0.90
Crossbred ⁴ male	−0.95	0.38	0.17	0.83	0.01	−0.71	0.49	0.10	1.59	0.28
STP ⁵	−0.11	0.89	0.65	1.22	0.49	−0.47	0.62	0.40	0.93	0.02
Birth weight	0.03	1.03	0.97	1.10	0.28	0.01	1.01	0.92	1.10	0.75
Assisted calving										
No	Referent	-	-	-	-	Referent	-	-	-	-
Yes	0.36	1.44	0.68	3.29	0.35	−0.37	0.68	0.19	1.85	0.49

Groups: Holstein female, crossbred female, crossbred male. ¹ Retrospective data were collected from 290 Holstein female calves and 89 Ang × Hol crossbred calves (46 males and 43 females) during the pre-weaning phase. ² Bovine Respiratory Disease. ³ Regression estimate. ⁴ Ang × Hol crossbred. ⁵ Serum total protein.

The descriptive data on the occurrence of BRD among the groups are presented in Figure 1b. The relative risk for the number of BRD cases in Holstein compared to crossbred animals did not differ between genetic compositions (RR: 1.59; 95% CI: 0.73–3.65; $p = 0.24$). The relative risk for the number of BRD cases did not differ among the groups, with Hol × Ang crossbred female (RR: 0.82; 95% CI: 0.30–2.06; $p = 0.67$) and Ang × Hol crossbred male (RR: 0.42; 95% CI: 0.11–1.28; $p = 0.14$) when compared to Holstein female calves. The age at the first case of BRD did not show differences between the groups (Holstein female: 37.0 ± 3.21 d, Ang × Hol crossbred female: 26.6 ± 9.01 d, Ang × Hol crossbred male: 37.8 ± 13.39 d; $p = 0.48$). The STP ($p = 0.02$) showed an association with the occurrence of BRD.

The overall mortality in the study was 2.8%. No deaths between Ang × Hol crossbred calves were recorded; however, 3.7% of Holstein calves died during the period of study.

3.4. Weaning Weight and ADG

Ang × Hol crossbred calves gained 0.14 kg more per day compared to Holstein calves (Ang × Hol crossbred: 1.43 ± 0.02 kg; Holstein: 1.29 ± 0.01 kg; $p < 0.01$). The ADG of the calves was different between groups ($p < 0.01$). Ang × Hol crossbred female calves gained 0.123 ± 0.04 kg more per day compared to Holstein calves ($p = 0.02$; Table 1). Ang × Hol crossbred male calves gained 0.166 ± 0.04 kg more per day compared to Holstein calves ($p < 0.01$; Table 1). Ang × Hol Crossbred female and male calves did not differ in ADG ($p = 0.74$; Table 1). Descriptively, the weaning weights were as follows: Ang × Hol crossbred females weighed 122 kg, Holstein females weighed 115 kg, and Ang × Hol crossbred males weighed 120 kg. The models for ADG and weaning weight included birth weight as a covariate.

We identified that ADG among animals affected by diarrhea did not differ compared to those that were not affected ($p = 0.33$; Figure 3a); and this was not associated with the calf's group ($p = 0.19$). Additionally, we found that animals affected by BRD also exhibited lower ADG compared to those that were not affected ($p < 0.01$; Figure 3b), but again, this was not associated with the group ($p = 0.15$).

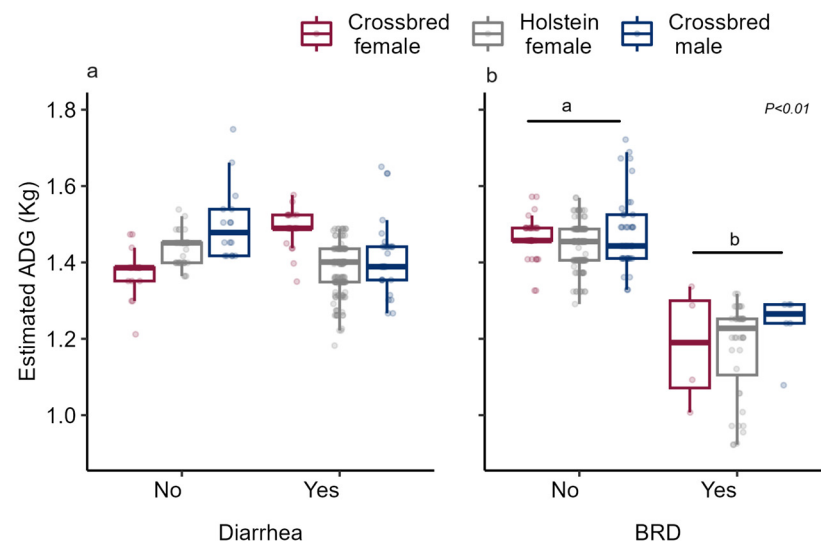


Figure 3. Impact of (a) diarrhea on ADG according to groups of calves. (b) BRD on ADG according to groups of calves. Different letters indicate statistical differences based on pairwise comparisons using the Tukey test. Error bars represent 95% CI.

4. Discussion

To our knowledge, this was the first study to measure the associations between genetic compositions (Holstein versus Ang $\times$ Hol crossbred calves) and health and performance parameters of calves reared under the same conditions and management during the pre-weaning phase. We observed that, despite the same rearing management, the genetic compositions differed in ADG and weaning weight levels. These results can be attributed to higher birth weight, increased concentrate consumption [10], and greater efficiency in weight gain [32], although we did not measure and collect dry matter intake data. Consistent with the results of this study, other researchers reported superior weight gain in beef $\times$ dairy crossbreds compared to pure dairy cattle [2,12]. We attributed the high weight gain of all calves evaluated in this study to the high milk volume provided to the animals [33], as well as to the use of pair housing [34,35] for the last third of the weaning phase. The volume of liquid diet provided in this study was double that used in the Pereira et al. [21], which likely influenced the higher weight gains observed. Early-life nutrition is correlated with good development [36,37], immune function, disease resistance [38], and it could impact future performance [39,40]. In addition, the effect of heterosis in Ang $\times$ Hol crossbred calves may have explained their better ADG due to changes in non-additive genetic effects of dominance and epistasis [41].

Another factor that may explain the higher weight gain observed in Angus $\times$ Holstein crossbred calves is the influence of additive genetics, which is attributed to the average genetic merit of the breeds involved in the crossbreeding process [41]. This results in offspring with enhanced economic potential, driven by novel combinations of additive genetic components [41]. In this context, it is possible that the increased weight gain is solely a consequence of the additive genetic contribution from the Angus breed, rather than being exclusively related to the crossbreeding itself. It is worth noting that the findings of the present study were based on evaluations of phenotypic traits (such as health and performance), and due to the experimental design, these findings could not differentiate between additive genetic effects and/or heterosis effects.

The difficulty of calving in Ang $\times$ Hol crossbred calves found in this study had previously been reported by Basiel et al. [42] and was believed to be related to birth weight [43]. The greater birth weight of Ang $\times$ Hol crossbred calves may have been influenced by heterosis factors [44], increased gestational duration [8,45], and may have

affected the likelihood of dystocia. Furthermore, we found that male calves had higher birth weights, which may have influenced the increased difficulty of calving [46].

The total protein did not differ among the group, supporting that the same management practices were applied to both genetic groups, which received adequate colostrum supply and timely administration [22]. The way Ang $\times$ Hol crossbred calves were raised in this study contrasted with management practices of crossbred and/or male dairy calves in other studies, where these animals were often under poorer welfare conditions [4,47,48]. A recent study showed that 32% of crossbred calves had poor STP classification (TPI < 5.1g/dL), with a higher risk of death compared to those with excellent passive transfer of immunity [21], indicating not only a deviation from the goals on passive immunity [49], but also serious husbandry issues that crossbred calves have been subjected to in rearing systems, compromising their welfare. Since we did not identify any effect of genetic compositions and group on STP, we decided not to elaborate on the effect of STP or TPI categories on ADG as this was not the primary hypothesis of our study. This relationship has been further explored by [21,50,51].

Contrary to our hypothesis that health status would be similar across genetic compositions, we found that Holstein calves were more frequently affected by diarrhea. This may be explained by heterosis, which enhances resistance to various stressors associated with mortality. Crossbred cattle tend to exhibit greater robustness compared to purebred animals due to the additional gene combinations they inherit [41,52]. Selection, even if indirect for disease tolerance, culminates in selection for greater stress tolerance in animals [53], which in this case may have reflected in fewer cases of diarrhea. A Danish study reported the positive effects of heterosis and demonstrated reduced frequencies of enteritis and mortality by more than half for crossbred animals aged 1 to 182 days [41]. Despite these hypotheses, more studies should investigate the effect of breed on disease tolerance. The lower incidence of diarrhea may have contributed to the lower mortality of Ang $\times$ Hol crossbred calves compared to Holstein calves, as diarrhea (digestive causes) accounts for 56.4% of dairy calf deaths in the pre-weaning period [54]. It is important to note that we did not observe a difference in BRD occurrence or the number of cases between the genetic compositions or groups. This could be related to the differences between genetic composition and/or the group being small. Thus, unfortunately, we only had the power to detect differences greater than 20%.

The impact of BRD and diarrhea on the ADG demonstrated for both genetic compositions used in this study had been assessed by others [55–57]. They showed that diarrhea and/or BRD positive calves gain less weight. The impact of diseases in early life is already correlated with increased age at first insemination [58], reduced milk production [17]. For cattle destined for slaughter, it has also been demonstrated that calves with a history of disease show reduced carcass weight [59,60]. Jaborek et al. [61] acknowledge that prior calf management subsequently affects future health, growth, finishing cattle performance, and carcass characteristics. They also affirmed that the industry must recognize that current management practices applied to purebred dairy calves raised for meat and those applied to beef-cross dairy calves may not always be appropriate and will need to be reassessed.

Our results highlight the importance of properly managing Ang $\times$ Hol crossbred calves to optimize their performance and promote their welfare. There is a significant opportunity in raising crossbred calves, which helps address concerns about the fate of surplus calves, particularly male calves from dairy breeds [62]. However, it is crucial to promote proper management in the rearing of crossbred calves, including adequate colostrum intake, umbilical cord care, liquid diet volume, vaccination practices, and disease prevention methods. Our results underscore the importance of ensuring that these crossbred calves receive such management from an early age, similar to dairy heifer calves, to achieve

optimal levels of development and performance. Otherwise, the use of beef-on-dairy may not effectively reduce the issues associated with surplus calves in the dairy industry and yet just creates another problem.

The occurrence of BRD in our study ranged from 11% to 14%, which is lower than the values reported by Fernandes et al. [63], who observed 26% of beef-on-dairy calves with lung consolidation at 61 days of age, and by Pereira et al. [21], who reported an incidence of approximately 55% in crossbred calves. Additionally, a study conducted on veal farms in the Netherlands showed that at least 38% of calves were clinically affected by BRD [64]. The occurrence of diarrhea was comparable to that reported by Pereira et al., who observed over 60% of affected calves, and by Pharo et al. [65], who reported that 63.8% of crossbred calves were treated for diarrhea. In terms of performance, the ADG in our study exceeded 1000 g/day, whereas Pereira et al. [21] reported gains below 600 g/day. These discrepancies may reflect differences in the management practices employed or differences in how the data were collected in each study.

Limitations

We recognized that our data did not allow for assessment of disease severity and treatment used in each case, which affected the feasibility of testing further hypotheses on health resiliency between genetic compositions. We also acknowledge that we only measured body weight at birth and weaning, which may have limited the ability to assess growth dynamics during the pre-weaning phase. Additionally, the use of chest girth tape and the frequency of weight measurements may have influenced the ability to obtain more detailed results, as chest girth tape is an indirect method of weight measurement [66]; however, both the frequency of measurements and the use of chest girth tape were applied uniformly to all calves. It is worth noting that chest girth tape is considered the most reliable measurement for predicting body weight in both purebred and crossbred cattle compared to withers height, body length, chest depth, hip width, and hip height [28,67]. Despite this, our study is pioneering in these comparisons, which may trigger and encourage further research that allows for better understanding. We emphasize that our findings specifically apply to the Angus × Holstein crossbreed and should not be extrapolated to other types of crossbreeding.

Future studies should more thoroughly assess the epidemiology of diseases in crossbred calves versus Holstein calves, using a larger number of animals to allow for detection of even smaller differences in disease incidence. As it was an observational study, the dams were not randomized. However, cows that gave birth to crossbred calves likely did not possess the same genetic background and farm history as those that gave birth to purebred Holstein calves, potentially biasing the results. This could explain why differences were not found in some analyzed variables. Nevertheless, the results still reflect the management practices of a commercial farm, even with possible differences in dam characteristics.

5. Conclusions

These results highlight that, under the same environment and management practices, Ang × Hol crossbred calves exhibit fewer cases and lower probability of diarrhea occurrence, along with greater ADG compared to Holstein dairy calves. Effective management practices are crucial for mitigating health issues and ensuring proper development, especially during the pre-weaning phase. Therefore, while beef production from dairy cows represents a promising strategy for the economic sustainability of dairy farms, it is essential to ensure good management practices to guarantee the welfare and healthy development of Ang × Hol crossbred calves.

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