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Growth Biology

Exploring associations among morphometric measurements, genetic group of sire, and performance of beef on dairy calves

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ABSTRACT

Sire selection for beef on dairy crosses plays an important role in livestock systems as it may affect future performance and carcass traits of growing and finishing crossbred cattle. The phenotypic variation found in beef on dairy crosses has raised concerns from meat packers due to animals with dairy-type carcass characteristics. The use of morphometric measurements may help to understand the phenotypic structures of sire progeny for selecting animals with greater performance. In addition, due to the relationship with growth, these measurements could be used to early predict the performance until the transition from dairy farms to sales. The objectives of this study were 1) to evaluate the effect of different beef sires and breeds on the morphometric measurements of crossbred calves including cannon bone (CB), forearm (FA), hip height (HH), face length (FL), face width (FW) and growth performance; and (2) to predict the weight gain from birth to transition from dairy farms to sale (WG) and the body weight at sale (BW) using such morphometric measurements obtained at first days of animals' life. CB, FA, HH, FL, FW, and weight at 7 ± 5 d (BW7) (Table 1) were measured on 206 calves, from four different sire breeds [Angus (AN), SimAngus (SA), Simmental (SI), and Limousin (LI)], from five farms. To evaluate the morphometric measurements at the transition from dairy farms to sale and animal performance 91 out of 206 calves sourced from four farms, and offspring of two different sires (AN and SA) were used. To predict the WG and BW, 97 calves, and offspring of three different sires (AN, SA, and LI) were used. The data were analyzed using a mixed model, considering farm and sire as random effects. To predict WG and BW, two linear models (including or not the morphometric measurements) were used, and a leave-one-out cross-validation strategy was used to evaluate their predictive quality. The HH and BW7 were 7.67% and 10.7% higher ($P < 0.05$) in SA crossbred calves compared to AN, respectively. However, the ADG and adjusted body weight to 120 d were 14.3% and 9.46% greater ($P < 0.05$) in AN compared to SA. The morphometric measurements improved the model's predictive performance for WG and BW. In conclusion, morphometric measurements at the first days of calves' life can be used to predict animals' performance in beef on dairy. Such a strategy could lead to optimized management decisions and greater profitability in dairy farms.

Lay Summary

The use of morphometric measurements, due to their relationship with growth, could be used to predict performance early. The objectives of this study were: 1) to evaluate the effect of beef sires and breeds, on the morphometric measurements of beef on dairy calves including cannon bone, forearm, hip height (HH), face length, face width, and growth performance; and 2) improve the accuracy of predicting weight gain (WG) from birth to transition of dairy animals from farms to sale, as well as their weight at sale (BW), using morphometric measurements which can be taken during the early days of their life. The HH and weight at 7 ± 5 d were 7.67% and 10.7% higher in SimAngus crossbred calves compared to Angus. More importantly, the variation among sires accounted for approximately 35% and 52% of all within-breed variation for morphometric measurements and weight during the first days of the animals' lives. The sentence highlights the importance of sire selection for beef on dairy crosses, as this decision can either lessen or worsen calving issues. In addition, morphometric measurements improved the model's ability to predict WG and BW. Consequently, this could assist farms in making earlier and more profitable decisions in dairy farming.

Key words: beef semen, beef on dairy, crossbreeding, forecast, Holstein

Abbreviations: ADG: Average daily gain; AIC: Akaike information criterion; AN: Angus; BW: Weight at the transition from dairy farms to sale; CB: Cannon bone; FA: Forearm; FL: Face length; FW: Face width; HH: Hip height; LI: Limousin; SA: SimAngus; SI: Simmental; BW7: Weight at 7 ± 5 d; WG: Weight gain

INTRODUCTION

The use of beef semen on dairy cows has been used as a strategy to increase profitability in dairy production systems (Weigel, 2004; Cabrera, 2021; Wolfova et al., 2007). Although this approach is not recent (Berry, 2021), in the last few years (from 2016 to 2019) the frequency of insemination with beef breeds

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in dairy cows increased 2.5 times in the United States, compared to the previous four years (McWhorter et al., 2020). Such a high growth rate in the use of beef semen on dairy cows was mainly due to the adoption of sexed semen, which reduced the number of rearing dairy heifers (Overton and Dhuyvetter, 2020).

Although beef on dairy crosses can improve cash flow in dairy farms (Berry, 2021), beef farms and meat packing plants have depreciated these animals, compared to standard beef breeds (e.g., Angus, Simental, Limousin, and Hereford), because of the perception of high heterogeneity in meat cuts and body conformation (Berry and Ring, 2020). The low carcass quality in beef on dairy crosses can be attributed to the long years of genetic selection for milk production that produced larger, angular, and low-fat cows (Berry et al., 2004). In this context, the selection of beef sires with expected progeny differences or predicted transmission capacity for desired traits such as meat and carcass quality seem to be a potential alternative to produce beef on dairy crosses with more standard body shape and carcass traits (Berry et al., 2019).

Sire selection for beef on dairy crosses is often challenging as such a decision is not made based on carcass traits or variables related to beef cattle performance. Usually, such a decision is made considering characteristics such as easy calving, gestation time (Berry et al., 2019; Berry and Ring, 2020), and price. In the United States, Angus (AN) is the main sire breed used for beef on dairy, representing 95.4% of the crosses (McWhorter et al., 2020). However, other breeds such as Simmental (SI), Limousin (LI), and SimAngus (Simmental/Angus; SA) are also being used due to their good market valuation and incentives from breeding associations (Basiel and Felix, 2022; Pereira et al., 2022).

Sires utilized for beef on dairy crosses are not well reported on commercial farms. Studies with this objective can guide the selection of breeds or even specific sires most suitable for the production system. In addition, a better understanding of the phenotypic structures of the beef on dairy progenies of these sires through the measurement of cannon bone (CB), face length (FL), face width (FW), forearm (FA), and hip height (HH) can demonstrate which calves are more similar to dairy or beef breeds at an early age and may help farmers in the selection of animals with better performance and/or may help make management and nutritional decisions.

To date, these morphometric measurements have been used to describe the growth of calves using different diets and nutritional strategies (Arrayet et al., 2002; Wickramasinghe et al., 2019) and to understand the association of growth characteristics with milk production in heifers (Van De Stroet et al., 2016). However, using such measurements to predict the future performance of calves, to the best of our knowledge, is new and not yet explored. In this context, this study aimed to evaluate: 1) the effect of different beef breeds and sires on the morphometric measurement variation including CB, FA, HH, FL, FW, and performance of crossbred calves, and 2) the use of morphometric measurements (e.g., CB, FA, HH, FL, and FW) to improve the accuracy of prediction of weight gain from birth to transition from dairy farms to sale (WG) and the body weight at the transition from dairy farms to sale (BW) in beef on dairy calves.

MATERIALS AND METHODS

Animal Care

All animal evaluations were approved by the Institutional Animal Care and Use Committee (IACUC) of the University of Wisconsin-Madison, protocol number A006270-R01.

Data and Statistical Analyses

Characterization of calves at first days of life Morphometric measurements including CB, FA, FL, and FW were collected using a plastic tape, and HH was assessed using an altitude stick (Figure 1). To evaluate the effect of different beef breeds as well as variation among sires within breeds on morphometric measurements at first days of life, 206 calves [7.1 ± 5.03 σ days of age; 133 males (M) and 73 females (F)] from five commercial farms and born between February and November of 2021 were analyzed. Only beef on dairy crosses born from Holstein cows were evaluated in this study. A total of 26 different sires (10 AN, 8 SA, 6 SI, and 2 LI) were used on such crosses. All animals were also weighed using an electronic digital scale (Table 1).

Different models were used according to the objectives of this study. To evaluate the effect of different breeds on morphometric measurements and weight at 7 ± 5 d (BW7), data were analyzed using a mixed model described as:

$$Y_{ijkl} = \mu + B_i + S_j + \beta * A_{ijkl} + F_k + e_{ijkl} \quad \text{(Model I)}$$

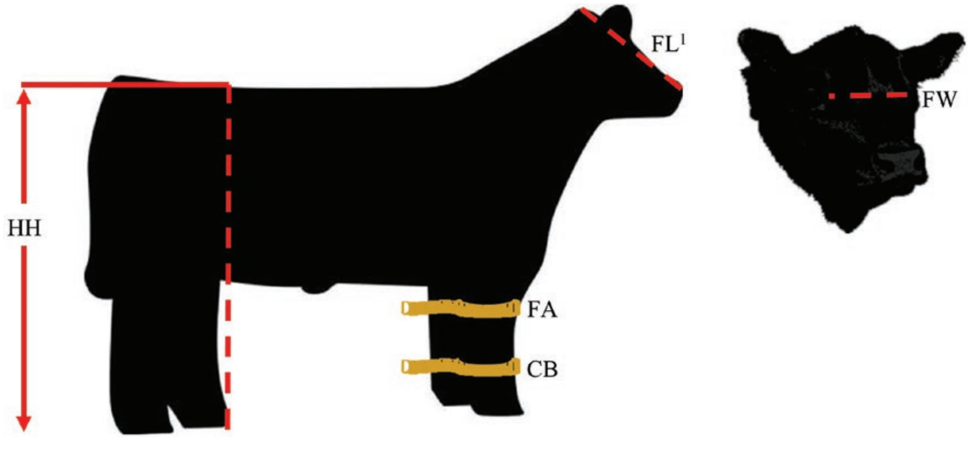

Figure 1. Description of measurement sites for morphometric variables. [1]FL = face length; FW = face width; FA = forearm; CB = cannon bone; HH = hip height.

Table 1. Descriptive statistics of morphometric measurements, weight, and gain

Variables[1]	N[2]	Mean	SD[3]	Median	Minimum	Maximum
All animals (variables calculated at 7 ± 5 d)						
Age of calves, d	206	7.10	5.03	5.00	1.00	31.0
Cannon bone, cm	206	12.0	0.87	12.0	10.0	14.0
Forearm, cm	206	20.5	1.68	20.0	17.0	25.5
Hip height, cm	206	81.7	5.24	81.0	70.0	104
Face length, cm	204	22.4	1.77	22.0	18.0	27.0
Face width, cm	204	13.1	1.01	13.0	10.5	15.5
Initial weight, kg	205	46.7	7.18	46.3	27.2	72.1
Animals with final observation (variables calculated at 7.7 ± 5 d used for animal evaluation at transition from dairy farms to sale)						
Age of calves, d	91	7.69	4.99	6.00	1.00	31.0
Cannon bone, cm	91	12.8	0.94	12.0	10.0	14.0
Forearm, cm	91	20.4	1.60	20.0	17.0	24.5
Hip height, cm	91	82.8	6.11	81.0	72.0	104
Face length, cm	91	22.8	1.96	23.0	19.0	27.0
Face width, cm	91	13.2	0.92	13.0	11.0	15.0
Initial weight, kg	91	47.7	7.34	47.0	31.0	72.0
Animals with final observation (variables at transition from dairy farms to sale calculated at 119 ± 11 d)						
Age of calves, d	91	119	10.9	121	104	146
Cannon bone, cm	87	16.7	4.49	15.0	12.0	29.0
Forearm, m	87	23.8	4.69	25.5	14.0	33.0
Hip height, m	91	106	4.33	105	97	117
Face length, cm	88	31.9	1.84	32.0	27.0	36.0
Face width, cm	90	16.5	2.56	16.0	13.5	32.0
ADG, kg/day	91	0.89	0.18	0.88	0.45	1.28
BW, kg	91	154	24.6	153	93.0	229
Animals with final observation (variables calculated at 7.1 ± 4 d used for prediction WG and BW)						
Age of calves, d	97	7.12	4.37	6.00	1.00	24.0
Cannon bone, cm	97	12.1	0.92	12.0	10.0	14.0
Forearm, cm	97	20.4	1.55	20.0	17.0	24.5
Hip height, cm	97	82.6	5.98	81.0	72.0	104
Face length, cm	97	22.8	1.91	23.0	19.0	27.0
Face width, cm	97	13.2	1.05	13.0	11.0	18.0
Initial weight, kg	97	47.1	7.33	46.0	27.2	72.0
Animals with final observation (variables calculated at 122 ± 15 d used for prediction WG and BW)						
Age of calves, d	97	122	14.7	121	104	165
Cannon bone, cm	97	14.8	1.08	15.0	12.0	17.5
Forearm, cm	97	26.1	2.14	26.0	21.0	33.0
Hip height, cm	97	106	4.40	106	97.0	117
Face length, cm	97	31.6	3.22	32.0	13.0	36.0
Face width, cm	97	16.5	2.49	16.0	13.5	32.0
Weight gain, kg	97	109	27.9	105	47.0	187
BW, kg	97	157	26.9	154	93.0	229

[1]ADG = average daily gain; WG = weigh gain; BW = weight at the transition from dairy farms to sale.
[2]*N* = number of animals.
[3]SD = standard deviation.

where y_{ijkl} represents the response variable of interest (CB, FA, FL, FW, HH, or BW7); μ is the model intercept; B_i is the fixed effect of the *i*th breed (*i* = AN, SA, SI, and LI), S_j is the fixed effect of the *j*th sex of calf (*j* = males and females), F_k is the random effect of farm (four farms: 1, 2, 3, 4, and 5), and β is the slope related to the age A_{ijkl} of animal *ijkl*; and e_{ijkl} is the independent identically distributed normal error.

Morphometric measurements of calves at the transition from dairy farms to sale. To evaluate morphometric measurements at the transition from dairy farms to sale, 91 calves (119 ± 11 d of age; 63 males and 28 females) from four commercial farms, offspring of 16 different sires (9 AN and 7 SA) were selected from the initial 206 calves. The reduction in the number of calves used was because three calves died, and 106 calves were sold before the end of the trial. Due to the small number of Simmental and Limousin sires, the Simmental × Holstein and Limousin × Holstein calves were not included in the study (Table 1).

To evaluate morphometric measurements at the transition from dairy farms to sale, the initial and final age of the calves, as well as the morphometric measurements were adjusted to 14 and 120 d, respectively. Age at sale was adjusted for 120 d (average age of calves at the transition from dairy farms to sale) because the farms do not have the same sales strategy for beef on dairy calves. For such adjustments, daily increments (x) for each morphometric measurement were calculated as:

$$x = \frac{(m_2 \quad m_1)}{A_T}$$

where m_2 represents the final morphometric measurement or BW, m_1 represents the initial measurement or BW, and A_T represents calf age at transition from dairy farms to sale. Then, the morphometrics traits were adjusted for 14 d (Ip_{14}) as:

$$\mathrm{Ip}_{14} = \mathrm{Ip} + [(14 - I_A) * x]$$

where Ip represents the initial morphometric measurement; I_A represents the age at the initial measurement; and x represents the daily growth of the morphometric measure as described above. Similarly, the morphometric traits were adjusted for120 d (fp_{120}) as:

$$\mathrm{fp}_{120} = \mathrm{fp} + [(120 - A_T) * x]$$

where fp represents the morphometric measurement at the transition from dairy farms to sale, A_T represents calf age at transition from dairy farms to sale, and x is as before.

After adjusting the CB, FA, FL, FW, and HH, two models were tested, using either only farm as a random effect (model II) or using both farm and sire as random effects (model III). After evaluating models II and III using the Akaike Information Criterion (AIC) as the model selection criterion. Model III presented, for most variables, the lowest AIC and it was then selected to fit the morphometric measures for calves at the transition from dairy farms to sale. Models II and III can be described as:

$$Y_{ijkl} = \mu + B_i + S_j + F_k + e_{ijkl} \quad \text{(Model II)}$$

$$Y_{ijklm} = \mu + B_i + S_j + F_k + R_l + e_{ijklm} \quad \text{(Model III)}$$

where y_{ijkl} and y_{ijklm} represent the response variable of interest (CB, FA, FL, FW, or HH); μ is the model intercept; B_i is the fixed effect of the ith breed (i = AN and SA), S_j is the fixed effect of the jth sex (j = males and females); F_k is the random effect of the farm (four farms: commercial farm 1, 2, 3, and 4), R_l is the random effect of sire (16 Sires: 9 AN and 7 SA) and e_{ijkl} and e_{ijklm} are the independent identically distributed normal errors.

Weight adjusted and average daily gain of calves. To evaluate ADG and adjusted weights the same 91 calves described in section "Characterization of calves at first days of life" were used (Table 1). To analyze BW, the weight at first days of life and the BW were adjusted to 14 and 120 d, respectively, using the following equations:

$$W_{14} = \mathrm{BW7} + [(14 - I_A) * \mathrm{ADG}]$$

and

$$\mathrm{aBW}_{120} = \mathrm{BW} + [(120 - A_T) * \mathrm{ADG}],$$

where W_{14} and $a\mathrm{BW}_{120}$ represent the adjusted weights for 14 and 120 d, respectively; BW7 represents the weight at first days of life; BW represents the weight at the transition from dairy farms to sale; I_A represents the age at measurement for BW7; A_T represents calf age at transition from dairy farms to sale; and ADG represents the average daily gain.

To remove the effects associated with bone size (e.g., size of animal, head size, and front legs size) on weight and ADG, all morphometric measurements (CB, FA, HH, FL, and FW) were used as fixed effects to fit models IV and V, while farm or farm and sire were used as random effects, respectively. After comparing models IV and V using the AIC criterion, model IV presented the lowest AIC and was used to compare weights adjusted for 14 d, ADG, and adjusted body weight to 120 d across breeds.

$$Y_{ijkl} = \mu + B_i + S_j + \beta * \mathrm{MM}_{ijkl} + F_k + e_{ijkl} \quad \text{(Model IV)}$$

$$Y_{ijklm} = \mu + B_i + S_j + \beta * \mathrm{MM}_{ijklm} + F_k + R_l + e_{ijklm} \quad \text{(Model V)}$$

where y_{ijkl} and y_{ijklm} represent the response variables of interest (W14, ADG, and $a\mathrm{BW}_{120}$); μ is the model intercept; B_i is the fixed effect of the ith breed (i = AN and SA), S_j is the fixed effect of the jth sex of calf (j = males and females); F_k is the random effect of farm (four farms: commercial farm 1, 2, 3, and 4), R_l is the random effect of sire (16 Sires: 9 AN and 7 SA), and βis the slope related to each morphometric measurements (CB + FA + HH, + FL, and FW) MM_{ijkl} and MM_{ijklm} of animal $ijkl$ and $ijklm$; and e_{ijkl} and e_{ijklm} are the independent identically distributed normal errors.

For all models (I to V), residual analysis was performed to verify the model assumptions of normality and homogeneous variances. Statistical differences were considered at the 5% level based on the ANOVA F test. When significant, means were compared using the Tukey test at 5% probability. All analyzes were performed using the statistical software R (R Core Team, 2019).

Prediction of Total Weight Gain and Weight at the Transition From dairy Farms to Sale

The use of morphometric measurements at the first days of life to predict BW and WG was evaluated in 97 calves (122 ± 15 d of age; 65 males and 32 females), from four commercial farms, offspring of 17 different sires (9 AN, 7 SA, and 1 LI), selected from the initial 206 calves (Table 1). Before building the predictive models, we utilized Pearson correlation to evaluate the intercorrelation among age, weight, average daily gain, and morphometric measurements (CB, FA, HH, FL, and FW). This step was taken to justify their inclusion in the linear model. Two linear models were used to predict WG and BW. The first model included the effects of sire,

Table 2. Morphometric measurements and weight with different genetic groups

Treatment						*P*-values		
Variables	Nº	Angus	SimAngus	Limousin	Simmental	*B*	G	IA
All animals (variables calculated at 7 ± 5 d)								
Cannon bone, cm	206	11.9 ± 0.15	12.1 ± 0.16	11.8 ± 0.31	11.8 ± 0.20	0.498	<0.001	0.579
Forearm, cm	206	20.3 ± 0.285	20.4 ± 0.305	20.0 ± 0.593	20.5 ± 0.383	0.824	<0.001	0.044
Hip height, cm	206	79.5 ± 1.24^{b}	85.6 ± 1.31^{a}	82.1 ± 2.69^{ab}	80.5 ± 1.55^{ab}	0.018	0.022	<0.001
Face length, cm	204	21.7 ± 0.64	21.9 ± 0.68	22.5 ± 0.85	22.6 ± 0.70	0.371	<0.001	0.108
Face width, cm	204	13.0 ± 0.17	12.9 ± 0.19	13.4 ± 0.35	13.1 ± 0.23	0.803	<0.001	0.018
Initial weight, kg	205	44.1 ± 0.91^{b}	48.8 ± 0.99^{a}	45.8 ± 1.86^{ab}	46.3 ± 1.26^{ab}	0.029	<0.001	<0.001
Animals with final observation (variables calculated at 7.7 ± 5 d and adjusted to 14 d) [1]								
Cannon bone, cm	91	12.2 ± 0.20	12.3 ± 0.20	–	–	0.873	<0.001	–
Forearm, cm	91	20.1 ± 0.32	20.6 ± 0.34	–	–	0.366	<0.001	–
Hip height, cm	91	81.6 ± 1.70^{b}	87.9 ± 1.89^{a}	–	–	0.027	0.152	–
Face length, cm	91	22.3 ± 0.87	22.1 ± 0.94	–	–	0.846	<0.001	–
Face width, cm	91	13.1 ± 0.16	13.3 ± 0.15	–	–	0.346	0.017	–
Animals with final observation (Variables at the transition from dairy farms to sale calculated at 119 ± 11 d and adjusted to 120 d)[1]								
Cannon bone, cm	87	14.9 ± 0.24	14.8 ± 0.29	–	–	0.508	0.004	–
Forearm, cm	87	25.4 ± 0.44	25.5 ± 0.45	–	–	0.858	0.006	–
Hip height, cm	91	102 ± 1.08^{B}	109 ± 1.11^{A}	–	–	<0.001	0.689	–
Face length, cm	88	30.3 ± 0.84	31.2 ± 0.93	–	–	0.193	0.174	–
Face width, cm	90	16.9 ± 1.35	16.5 ± 1.58	–	–	0.828	0.815	–

[a–b]Means within a column with no superscripts in common are different at $P < 0.05$.
[A–B]Means within a column with no superscripts in common are different at $P < 0.01$.
Standard error was used as a measure of variability in the statistical analysis.

sex, BW7, and age (model VI). The second model (model VIII) included the effects of sire, sex, BW7, age, and the morphometric measurements (CB, FA, HH, FL, and FW). The models can be described as:

$$Y_{ijk} = \mu + B_i + S_j + \beta_1 * \mathrm{BW7}_{ij} + \beta_2 * A_{ijk} + e_{ijk} \quad \text{(Model VI)}$$

$$Y_{ijk} = \mu + B_i + S_j + \beta_1 * W7_{ijk} + \beta_2 * A_{ij} + \beta_3 * \mathrm{MM}_{ijk} + e_{ijk} \quad \text{(Model VII)}$$

where y_{ijk} represents the observed WG and BW; μ is the model intercept; B_i is the effect of the *i*th breed (*i* = AN, SA, and LI), S_j is the effect of the *j*th sex (*j* = males and females); β_1 is the slope related to the weight $BW7_{ijk}$ of animal *ijk*; β_2 is the slope related to the age A_{ijk} of animal *ijk*; β_3 is the slope related to each morphometric measurements (CB + FA + HH, + FL, and FW) MM_{ijk} of animal *ijk* and e_{ijk} is the independent identically distributed normal errors.

To evaluate the predictive performance of both models, a leave-one-animal-out cross-validation was used. In this strategy, all information from a specific animal is excluded and used as a validation set, while the remaining information on the N-1 animals is used to build the linear regression model, and the process is repeated for each animal. To evaluate the predictive ability, root mean squared error of prediction (Bibby and Toutenburg., 1977), R^2, concordance coefficient of correlation (Liao, 2003), mean bias (Cochran and Cox, 1957), and AIC were calculated. All analyzes were performed using the statistical software R (R Core Team, 2019).

Results and Discussion

The present study investigated if morphometric measurements and animal performance differed among AN, SI, LI, and SA sires used to generate beef on dairy crossbred calves. The HH and BW7 were 7.67% and 10.7% higher ($P = 0.02$; $P = 0.03$) in SA crossbred calves compared to AN, respectively (Table 2). These findings are particularly important in dairy farms due to productive and financial losses related to calving difficulty (Berry and Ring, 2020). Although the present study did not assess calving ease, larger and heavier calves are more likely to cause dystocia (Naazie et al., 1989; Bragg et al., 2021). In addition, higher calf birth weight increases the risk of perinatal mortality (Johanson and Berger, 2003). According to Berry and Ring (2020), the selection of sire semen for meat production on a dairy farm cannot occur to the detriment of the health of cows. According to the authors, cows that required veterinary assistance or cesarean at calving increased the cost of production by 7.4 to 10 times compared to slight assistance, respectively.

Despite having lower initial body weight ($P = 0.02$), the adjusted body weight to 120 d was 9.46% higher ($P < 0.01$) in animals AN compared to SA. These results demonstrate the better performance of AN animals that had ADG 14.3% higher ($P = 0.01$) than SA during this phase (Table 3). In the present study, we did not follow the animals throughout the growing and finishing phase, thus it is still unclear whether the lower performance in SA animals during this phase would impact subsequent growing and fattening phases. In feedlots, Jaborek et al. (2019) evaluated the performance of beef on dairy (20 AN and 29 SA) animals and found no difference in weight gain. It is important to highlight that beef on dairy

Table 3. Performance in calves using morphometric measurements (kg)

Treatment[1]	Weight at first days of life [2]	aBW_{120}[3]	Average daily gain
Angus	52.5 ± 1.65[a]	162 ± 3.62[A]	0.96 ± 0.03[a]
SimAngus	56.4 ± 1.90[b]	148 ± 3.30[B]	0.84 ± 0.03[b]
P-values			
S	0.020	<0.01	0.013
G	0.582	0.396	0.217
CB	0.039	0.604	0.368
FA	0.002	0.316	0.242
HH	0.222	0.017	0.264
FL	0.003	0.011	0.008
FW	0.095	0.310	0.297
BW7	–	0.019	0.460

[a–b]Means within a column with no superscripts in common are different at $P < 0.05$.
[A–B]Means within a column with no superscripts in common are different at $P < 0.01$.
Standard error was used as a measure of variability in the statistical analysis.
[1]S = sire; G = sex; CB = cannon bone; FA = forearm; HH = hip height; FL = face length; FW = face width; BW7 = weight at 7 ± 5.
[2]Variables calculated at 7.7 ± 5 d and adjusted to 14 d.
[3]Variables calculated at 119 ± 11 d and adjusted to 120 d.

Table 4. Evaluation of morphometric measurements and weight models

Variables [1]		Variables calculated at first days of life[2]		Variables at transition to sal [3]	
		Model III	Model II	Model III	Model II
Cannon bone	AIC	236	240	238	238
	σ2S	0.17 ± 0.41	–	0.08 ± 0.28	–
	σ2F	0.000	0.000	0.08 ± 0.28	0.07 ± 0.26
	σ2Res.	0.57 ± 0.76	0.71 ± 0.84	0.70 ± 0.83	0.77 ± 0.88
Forearm	AIC	333	334	352	355
	σ2S	0.32 ± 0.57	–	0.93 ± 0.97	–
	σ2F	0.02 ± 0.15	0.05 ± 0.23	0.000	0.000
	σ2Res.	1.80 ± 1.34	2.05 ± 1.43	2.51 ± 1.59	0.36 ± 0.77
Hip height	AIC	499	549	551	556
	σ2S	23.1 ± 4.80	–	4.63 ± 2.51	–
	σ2F	0.000	0.000	0.000	0.000
	σ2Res.	8.82 ± 2.97	23.8 ± 4.88	21.2 ± 4.60	25.6 ± 5.06
Face length	AIC	333	332	357	355
	σ2S	0.20 ± 0.45	–	0.16 ± 0.40	–
	σ2F	2.56 ± 1.60	2.40 ± 1.55	2.20 ± 1.48	2.16 ± 1.47
	σ2Res.	1.71 ± 1.31	1.86 ± 1.36	2.70 ± 1.64	2.81 ± 1.68
Face width	AIC	246	245	334	412
	σ2S	0.04 ± 0.20	–	12.9 ± 3.60	–
	σ2F	0.000	0.000	1.08 ± 1.04	3.32 ± 1.82
	σ2Res.	0.71 ± 0.84	0.75 ± 0.86	1.09 ± 1.04	4.95 ± 2.23

[1]AIC = Akaike information criterion; S = Sire; F = Farm; Res = Residual.
[2]Variables calculated at 7.7 ± 5 d and adjusted to 14 d.
[3]Variables calculated at 119 ± 11 d and adjusted to 120 d.

crosses may have a longer production cycle, 16 to 18 months (Berry, 2021), so that larger and long-term experiments evaluating the effect of sires on beef on dairy crosses performance are needed.

Sire, on average, accounted for 35% of all within-breed variation for the morphometric measurements on first days of animals' life (Table 4) and 52% in weights adjusted for 14 d (Table 5). Despite the small number of bulls evaluated, these results demonstrate that the decision on selecting beef sires to produce beef on dairy crosses may positively or negatively affect calving problems in dairy farms by altering body weight and morphometric characteristics (Martin-Collado et al., 2017). Besides the choice of breed, it is equally, if not more, important to select specific sires that do not contribute to increased calving problems in their crossbred progeny.

Table 5. Evaluation of models to average daily gain and weight at the transition from dairy farms to sale

Variables[1]		Variables at transition to sale	
		Model V	Model IV
Weight at first days of life[2]	AIC	516	538
	σ2S	13.1 ± 3.63	–
	σ2F	0.000	6.88 ± 2.62
	σ2Res.	11.9 ± 3.45	20.1 ± 4.48
Average daily gain[3]	AIC	12.6	10.6
	σ2S	0.000	–
	σ2F	0.000	0.000
	σ2Res.	0.03 ± 0.17	0.03 ± 0.17
aBW_{120}[3]	AIC	779	777
	σ2S	0.000	–
	σ2F	0.000	0.000
	σ2Res.	382 ± 19.6	382 ± 19.6

[1]AIC = Akaike information criterion; S = sire; F = farm; Res = residual; aBW_{120} = weight at the transition from dairy farms to sale adjusted for 120 d.
[2]Variables calculated at 7.7 ± 5 d and adjusted to 14 d.
[3]Variables calculated at 119 ± 11 d and adjusted to 120 d.

The inclusion of morphometric measurements (e.g., CB, FA, HH, FL, and FW) in the prediction model using sire, sex, BW7, and calf age at transition from dairy farms to sale improved the prediction of WG and BW (Figure 2; Table 6). These models could be used as a valuable decision-making tool for early identification of the top and bottom animals and implement management actions in a timely manner as a way to minimize economic losses and increase farm profitability. Such management decisions could include the slaughter of bottom animals such as veal (Renaud and Pardon., 2022) or finish the top animals using conventional beef cattle practices (Berry, 2021). For BW, the body measurements increased the values of R^2 (from 0.31 to 0.36), and concordance coefficient of correlation (from 0.49 to 0.56), and reduced the AIC values from 873 to 865 (Table 6). The use of morphometric measurements also reduced mean bias (from 0.05 to 0.02 kg) and root mean squared error of prediction (from 22.5 to 21.8 kg). For WG prediction with morphometric variables, the values of mean bias, root mean squared error of prediction and AIC were equal to the model for BW prediction. However, morphometric measurements increased the R^2 (from 0.35 to 0.40) and concordance coefficient of correlation (from 0.54 to 0.60). The improvement in prediction with the inclusion of initial morphometric measurements might be

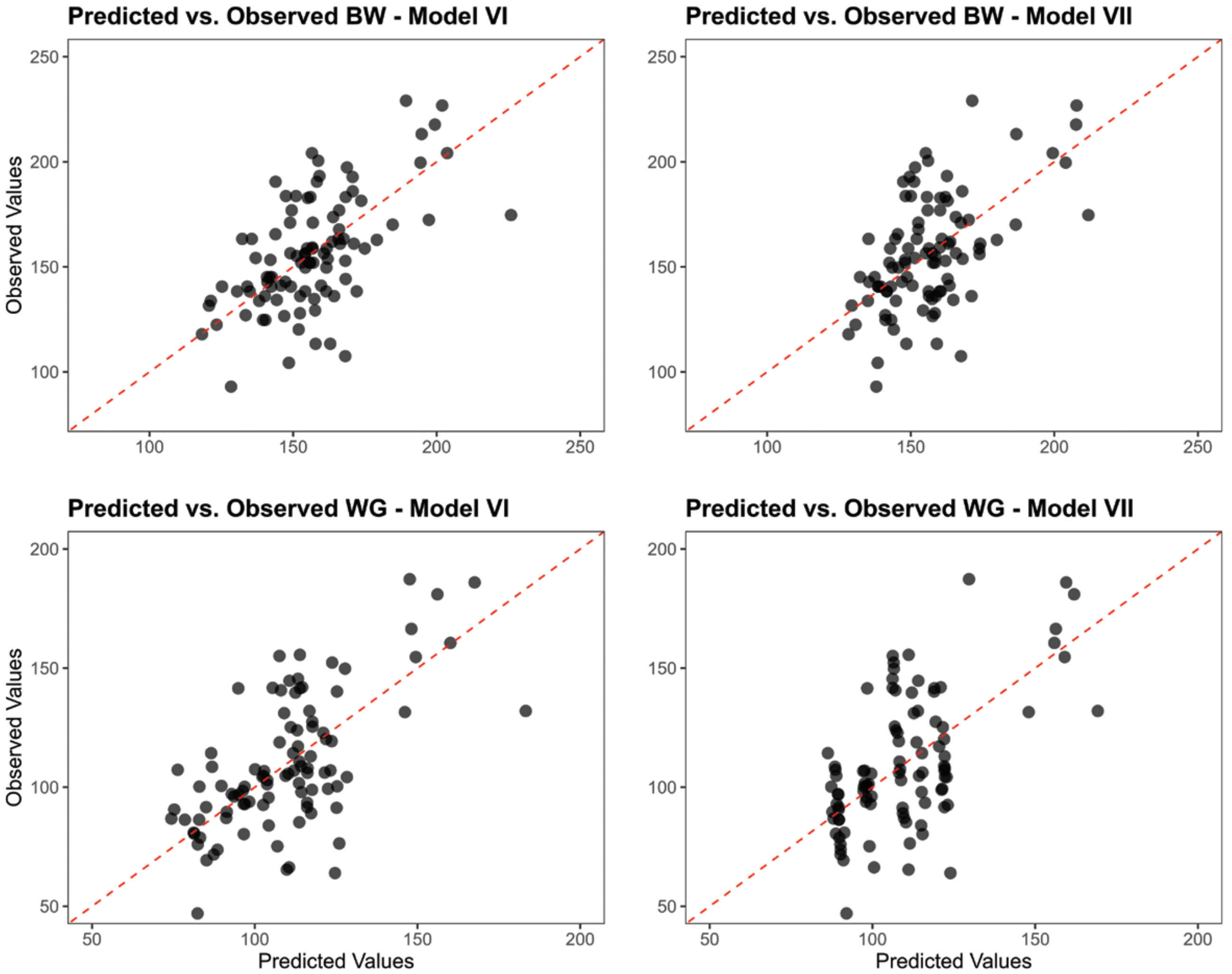

Figure 2. Relationships between predicted and observed variables. WG = weigh gain; BW = weight at the transition from dairy farms to sales.

Table 6. Evaluation between predicted model values and observed data

Variables[1]		BW[2]			Weight gain	
	Obs	Modelo VI	Modelo VII	Obs	Model V	Model VII
Mean	157	157	157	109	109	109
AIC		865	873		865	873
R^2		0.357	0.305		0.397	0.349
MB		0.018	0.045		0.018	0.045
CCC		0.563	0.494		0.599	0.539
RMSEP		21.8	22.5		21.8	22.5

[1]AIC = Akaike information criterion; MB = mean bias; CCC = concordance correlation coefficient; RMSEP = root squares mean prediction error.
[2]BW = weight at the transition from dairy farms to sale.

due to the low intercorrelation with BW7 and calf age at the transition from dairy farms to sale and CB, FA, HH, FL, and BW, which could potentially explain the improvement in the model performance (Kim, 2019).

In the present study, we used morphometric measurements in beef on dairy crosses to predict their WG and BW. The morphometric measurements were obtained using tape measurement, following similar protocols widely used in dairy farms. However, on a larger scale, tape can be labor-intensive and difficult to perform in practice (Bewley et al., 2001; Bezsonov et al., 2021). In this context, new technologies such as computer vision can collect morphometric measurements (Cominotte et al., 2020; Oliveira et al., 2021), enabling large-scale phenotyping collection. Ruchay et al. (2020) evaluated the accuracy of depth cameras to measure body biometrics (e.g., wither height, hip height, and hip length) in cattle, and reported that the difference normalized between the camera and manual measurements were less than 2 cm. Shi et al. (2019) also reported the great potential of computer vision systems to predict ($R^2 > 0.82$ and RMSE < 2.9 cm compared to manually collected) pigs' body measurements (e.g., body length, body width, body height, hip width, and hip height). Song et al. (2018) evaluated the improvement in prediction BW from days of lactation, age, and parturition, when morphometric measurements (e.g., hip height, rump length, and hip width) collected using 3D cameras or manually were included. The manual and automated measurements achieved similar performance. According to the authors, to improve the model it is important to select other predictive characteristics.

In this context, other variables such as dry matter intake, energy intake (Azevedo et al., 2016; Terler et al., 2022), animal health (Morrison et al., 2019), among others, can influence WG and BW in calves and could improve the prediction of the model in this study. However, the results of the present study do not aim to evaluate the use of isolated morphometric measurements as predictors of weight gain but demonstrate that these variables can be used to improve the prediction performance. In the future, more complex models, such as deep neural networks (Okut et al., 2011; Srivastava et al., 2014), will be able to use the morphometric measurements together with a large number of other variables to make more assertive predictions. These are preliminary results but already indicate that these morphometric measurements can be successfully used for prediction and that higher predictive quality should be obtained when using a larger number of animals and sires.

Conclusions

Beef on dairy cross-bred calves showed some important differences in size and weight across breeds. More importantly, the variation among sires accounted for about 35% and 52% of all within-breed variation for the morphometric measurements and weight on first days of animals' life. This underscore the importance of the choice of sire to be used for beef on dairy crosses, as such a decision may positively or negatively affect calving problems. In addition, this study demonstrated that morphometric measurements (e.g., CB, FA, HH, FL, and FW) obtained early in the life of calves can be satisfactorily used to predict their future WG and BW and ultimately their overall performance.

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Conflict of interest statement

There are no potential conflicts of interest that may affect our ability to objectively present or review the research data submitted here.

Literature Cited

Arrayet, J. L., A. M. Oberbauer, T. R. Famula, I. Garnett, J. W. Oltjen, J. Imhoof, M. E. Kehrli, and T. W. Graham. 2002. Growth of Holstein calves from birth to 90 days: the influence of dietary zinc and BLAD status. *J. Dairy Sci.* 80:545–552. doi:10.2527/2002.803545x.

Azevedo, R. A., F. S. Machado, M. M. Campos, D. R. G. Lopes, S. F. Costa, H. C. Mantovani, F. C. F. Lopes, M. I. Marcondes, L. G. R. Pereira, T. R. Tomich, et al. 2016. The effects of increasing amounts of milk replacer powder added to whole milk on passage rate, nutrient digestibility, ruminal development, and body composition in dairy calves. *J. Dairy Sci.* 99:8746–8758. doi:10.3168/jds.2016-11410.

Basiel, B. L., and T. L. Felix. 2022. Board Invited Review: crossbreeding beef × dairy cattle for the modern beef production system. *Transl. Anim. Sci* 6:txac025. doi:10.1093/tas/txac025.

Berry, D. P. 2021. Invited review: beef-on-dairy—the generation of crossbred beef × dairy cattle. *J. Dairy Sci.* 104:3789–3819. doi:10.3168/jds.2020-19519.

Berry, D. P., P. R. Amer, R. D. Evans, T. Byrne, A. R. Cromie, and F. Hely. 2019. A breeding index to rank beef bulls for use on dairy females to maximize profit. *J. Dairy Sci*. 102:10056–10072. doi:10.3168/jds.2019-16912.

Berry, D. P., F. Buckley, P. G. Dillon, R. D. Evans, and R. F. Veerkamp. 2004. Genetic relationships among linear type traits, milk yield, body weight, fertility and somatic cell count in primiparous dairy cows. *Ir. J. Agric. Food Res*. 43:161–176.

Berry, D. P., and S. C. Ring. 2020. Observed progeny performance validates the benefit of mating genetically elite beef sires to dairy females. *J. Dairy Sci*. 103:2523–2533. doi:10.3168/jds.2019-17431.

Bewley, J., R. W. Palmer, and D. B. Jackson-Smith. 2001. An overview of experiences of Wisconsin dairy farmers who modernized their operations. *J. Dairy Sci*. 84:717–729. doi:10.3168/jds.S0022-0302(01)74526-2.

Bezsonov, O., O. Lebediev, V. Lebediev, Y. Megel, D. Prochukhan, and O. Rudenko. 2021. Breed recognition and estimation of live weight of cattle based on methods of machine learning and computer vision. *East.-Eur. J. Enterp. Technol*. 6:114. doi:10.15587/1729-4061.2021.247648.

Bibby, J., and H. Toutenburg. 1977. *Prediction and improved estimation in linear models*. 1st edn. Berlin: John Wiley & Sons.

Bragg, R., A. Macrae, S. Lycett, E. Burrough, G. Russell, and A. Corbishley. 2021. Risk factor analysis for beef calves requiring assisted vaginal delivery in Great Britain. *Vet. Rec*. 188:47–80. doi:10.1002/vetr.8.

Cabrera, V. E. 2021. Economics of using beef semen on dairy herds. *JDS Commun*. 3:147–151. doi:10.3168/jdsc.2021-0155.

Cochran, W. G. and G. M. Cox. 1957. *Experimental designs*, 2nd edn. New York: Wiley.

Cominotte, A., A. F. A. Fernandes, J. R. R. Dorea, G. J. M. Rosa, M. M. Ladeira, E. H. C. B. Van Cleeff, G. L. Pereira, W. A. Baldassinic, and O. Machado Neto. 2020. Automated computer vision system to predict body weight and average daily gain in beef cattle during growing and finishing phases. *Livest. Sci* 232:103904. doi:10.1016/j.livsci.2019.103904.

Jaborek, J. R., H. N. Zerby, S. J. Moeller, F. L. Fluharty, and A. E. Relling. 2019. Evaluation of feedlot performance, carcass characteristics, carcass retail cut distribution, Warner-Bratzler shear force, and fatty acid composition of purebred Jersey and crossbred Jersey steers. *Transl. Anim. Sci* 3:1475–1491. doi:10.1093/tas/txz110.

Johanson, J. M., and P. J. Berger. 2003. Birth weight as a predictor of calving ease and perinatal mortality in Holstein cattle. *J. Dairy Sci*. 86:3745–3755. doi:10.3168/jds.S0022-0302(03)73981-2.

Kim, J. H. 2019. Multicollinearity and misleading statistical results. *Korean J. Anesthesiol* 72:558–569. doi:10.4097/kja.19087.

Liao, J. J. Z. 2003. An improved concordance correlation coefficient. *Pharm. Stat*. 2:253–261. doi:10.1002/pst.52.

Martin-Collado, D., F. Hely, T. J. Byrne, R. Evans, A. R. Cromie, and P. R. Amer. 2017. Farmer views on calving difficulty consequences on dairy and beef farms. *Animal* 11:318–326. doi:10.1017/S1751731116001567.

McWhorter, T. M., J. L. Hutchison, H. D. Norman, J. B. Cole, G. C. Fok, D. A. L. Lourenco, and P. M. VanRaden. 2020. Investigating conception rate for beef service sires bred to dairy cows and heifers. *J. Dairy Sci*. 103:10374–10382. doi:10.3168/jds.2020-18399.

Morrison, S. Y., P. A. LaPierre, K. N. Brost, and J. K. Drackley. 2019. Intake and growth in transported Holstein calves classified as diarrheic or healthy within the first 21 days after arrival in a retrospective observational study. *J. Dairy Sci*. 102:10997–11008. doi:10.3168/jds.2019-16609.

Naazie, A., M. M. Makarechian, and R. T. Berg. 1989. Factors influencing calving difficulty in beef heifers. *J. Dairy Sci*. 67:3243–3249. doi:10.2527/jas1989.67123243x.

Okut, H., D. Gianola, G. J. Rosa, and K. A. Weigel. 2011. Prediction of body mass index in mice using dense molecular markers and a regularized neural network. *Genet. Res. (Camb)* 93:189–201. doi:10.1017/S0016672310000662.

Oliveira, D. A. B., L. G. R. Pereira, T. Bresolin, R. E. P. Ferreira, and J. R. R. Dorea. 2021. A review of deep learning algorithms for computer vision systems in livestock. *Livest. Sci* 253:104700. doi:10.1016/j.livsci.2021.104700.

Overton, M. W., and K. C. Dhuyvetter. 2020. Symposium review: an abundance of replacement heifers: what is the economic impact of raising more than are needed? *J. Dairy Sci*. 103:3828–3837. doi:10.3168/jds.2019-17143.

Pereira, J. M. V., D. Bruno, M. I. Marcondes, and F. C. Ferreira. 2022. Use of beef semen on dairy farms: a cross-sectional study on attitudes of farmer toward breeding strategies. *Front. Anim. Sci*. 2:1–10. doi:10.3389/fanim.2021.785253.

R Core Team. 2019. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Renaud, D., and B. Pardon. 2022. Preparing male dairy calves for the veal and dairy beef industry. *Vet. Clin. North Am. Food Anim. Pract*. 38:77–92. doi:10.1016/j.cvfa.2021.11.006.

Ruchay, A., V. Kober, K. Dorofeev, V. Kolpakov, and S. Miroshnikov. 2020. Accurate body measurement of live cattle using three depth cameras and non-rigid 3-D shape recovery. *Comput. Electron. Agric*. 179:105821. doi:10.1016/j.compag.2020.105821.

Shi, C., J. Zhang, and G. Teng. 2019. Mobile measuring system based on LabVIEW for pig body components estimation in a large-scale farm. *Comput. Electron. Agric*. 156:399–405. doi:10.1016/j.compag.2018.11.042.

Song, X., E. A. M. Bokkers, P. P. J. van der Tol, P. G. Koerkamp, and S. Van Mourik. 2018. Automated body weight prediction of dairy cows using 3-dimensional vision. *J. Dairy Sci*. 101:4448–4459. doi:10.3168/jds.2017-13094.

Srivastava, N., G. Hinton, A. Krizhevsky, I. Sutskever, and R. Salakhutdinov. 2014. Dropout: a simple way to prevent neural networks from overfitting. *J. Mach. Learn. Res*. 15:1929–1958..

Terler, G., G. Poier, F. Klevenhusen, and Q. Zebeli. 2022. Replacing concentrates with a high-quality hay in the starter feed in dairy calves: I. Effects on nutrient intake, growth performance, and blood metabolic profile. *J. Dairy Sci*. 105:2326–2342. doi:10.3168/jds.2021-21078.

Van De Stroet, D. L., J. C. Díaz, K. J. Stalder, A. J. Heinrichs, and C. D. Dechow. 2016. Association of calf growth traits with production characteristics in dairy cattle. *J. Dairy Sci*. 99:8347–8355. doi:10.3168/jds.2015-10738.

Weigel, K. A. 2004. Exploring the role of sexed semen in dairy production systems. *J. Dairy Sci*. 87:E120–E130. doi:10.3168/jds.S0022-0302(04)70067-3.

Wickramasinghe, H. K. J. P., A. J. Kramer, and J. A. D. R. N. Appuhamy. 2019. Drinking water intake of newborn dairy calves and its effects on feed intake, growth performance, health status, and nutrient digestibility. *J. Dairy Sci*. 102:377–387. doi:10.3168/jds.2018-15579.

Wolfova, M., J. Wolf, J. Kvapilık, and J. Kica. 2007. Selection for profit in cattle: II. Economic weights for dairy and beef sires in crossbreeding systems. *J. Dairy Sci*. 90:2456–2467. doi:10.3168/jds.2006-615.