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The impact of sire breed on feedlot performance and carcass characteristics of beef × Holstein steers

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Abstract

Dairy herds are mating a portion of cows to beef cattle semen to create a value-added calf. Objectives of this study were to compare the feedlot performance and carcass characteristics of beef × Holstein steers by breed when sires represented bulls with commercially available semen. Three groups of single-born, male calves ($n = 262$) born to Holstein dams on 10 Pennsylvania dairies were sourced during 3 yr. Steers were sired by seven beef breeds: Angus, Charolais, Limousin, Hereford, Red Angus, Simmental, and Wagyu. Steers were picked up within a week of age and raised at two preweaned calf facilities until weaning (8 ± 1 wk of age) under similar health and management protocols. Steers were then transported to a commercial calf growing facility where they were managed as a single group until 10 ± 2 mo of age when they were moved to be finished at the Pennsylvania Department of Agriculture's Livestock Evaluation Center feedlot. Groups of steers were selected for slaughter based on body weight. Carcass characteristics were evaluated by trained personnel and a three-rib section of the longissimus muscle (LM) was collected from each carcass for Warner-Bratzler shear force (WBSF) evaluation and intramuscular fat determination. Steers sired by all sire breeds except for Limousin had greater average daily gain (ADG; 1.62 to 1.76 kg/d) than Wagyu × Holstein steers (1.39 kg/d; $P < 0.05$). Angus-sired steers had an 8.6% greater ADG than Red Angus-sired steers ($P < 0.05$). Angus, Charolais (1.73 kg/d), and Simmental-sired steers (1.68 kg/d) also had greater ADG than Limousin-sired steers (1.55 kg/d; $P < 0.05$). Wagyu × Holstein steers spent 5 to 26 more days on feed ($P < 0.05$) than Limousin × Holstein, Simmental × Holstein, Angus × Holstein, and Charolais × Holstein steers. Angus and Charolais-sired steers were also on feed for 19 and 21 d fewer, respectively, than Limousin-sired steers ($P < 0.05$). Red Angus-sired steers had greater marbling scores than Simmental and Limousin-sired steers and Angus and Charolais-sired steers had greater marbling scores than Limousin-sired steers ($P < 0.05$). Angus, Limousin, and Hereford-sired steers produced the most tender LM as evaluated by WBSF; Angus-sired carcasses (3.82 kg) were more tender than Charolais (4.30 kg) and Simmental-sired carcasses (4.51 kg; $P < 0.05$). Limousin and Hereford-sired steers (3.70 and 3.83 kg, respectively) also had more tender steaks than Simmental-sired steers.

Lay Summary

An increasing portion of the national dairy herd is being mated to beef cattle semen to increase the value of surplus calves. This trial used calves born to Holstein dams sired by seven beef cattle breeds: Angus, Charolais, Limousin, Hereford, Red Angus, Simmental, and Wagyu. Steers were fed and managed similarly throughout life. Angus, Charolais, and Simmental-sired steers had 8% to 26% greater average daily gain than Wagyu and Limousin-sired steers. Wagyu and Limousin-sired steers were on feed for 19 to 26 d longer than Charolais and Simmental-sired steers. Carcasses were similar by sire breed, but Red Angus, Angus, and Charolais-sired steers had the greatest marbling scores (5.03, 4.82, and 4.71, respectively) while Simmental and Limousin-sired steers had the least marbling (4.50 and 4.14, respectively). Angus, Hereford, and Limousin-sired steers produced the most tender beef (3.82, 3.83, and 3.70 kg of force, respectively) and Simmental-sired steers produced the least tender beef (4.51 kg of force).

Key words: beef on dairy, carcass, dairy progeny, phenotype

Introduction

Throughout the United States, the number of dairy females being bred with beef breed semen has grown dramatically. These trends are reflected in the over 350% increase in domestic beef semen sales from 2017 to 2022 and the subsequent reduction in domestic dairy semen sales (NAAB, 2023). The increase in beef semen sales has been largely attributed to the dairy industry because over 90% of beef females in the United States are mated exclusively by natural service (USDA, 2020). The primary impetus for these mating decisions is to increase the value of surplus calves coming off the dairy farm (Basiel and Felix, 2022). The value of beef × dairy calves exceeds that of purebred dairy bull calves (McCabe et al., 2022), in some instances by several hundred dollars.

Survey results and evaluations of dairy herd management records suggest that Angus is the primary sire breed used in U.S. beef × dairy inseminations (McWhorter et al. 2020; Pereira et al., 2022; Felix et al., 2023; Lauber et al., 2023). This is reflected by the shift away from fed Holstein steers to black-hided beef × dairy animals reported in the most recent National Beef Quality Audit (NBQA, 2016, 2023). In 2022, only 12% of fed cattle had Holstein-colored hides, down from 20% in 2016, while black hides have increased by 4% (NBQA, 2016, 2023). However, other sire breeds will result in black-hided beef × dairy progeny as well. Dairies are using Limousin, Simmental, Charolais, Wagyu, Crossbred beef, and Hereford semen in beef × dairy matings (Pereira et al., 2022; Felix et al., 2023; Lauber et al., 2023). With the

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Table 1. Breakdown of beef × Holstein steers on feed by year and sire breed.

Year on feed	Sire breed	NAAB breed code	*n* steers	*n* sires	Sire NAAB code
2021	Angus	AN	12	6	7AN363, 7AN408, 7AN422, 7AN474, 7AN476, 7AN480
	SimAngus	SM	20	3	7SM68, 7SM84, 7SM98
2022	Angus	AN	21	4	7AN363, 7AN476, 7AN526, 7AN572
	Charolais	CH	79	3	7CH95, 9CH103, 9CH99
	Wagyu	KB	11	2	7KB1, 7KB2
	SimAngus	SM	16	2	7SM84, 7SM100
2023	Angus	AN	14	2	7AN579, 7AN624
	Charolais	CH	13	2	9CH105, 9CH106
	Red Angus	AR	28	2	7AR81, 7AR87
	Hereford	HP	19	2	7HP116, 14HP1037
	Limousin	LM	18	2	7LM14, 7LM20
	SimAngus	SM	7	1	7SM107
	Simmental	SM	4	1	7SM104

NAAB, National Association of Animal Breeders.

exception of Charolais, the aforementioned sire breeds can produce black-hided progeny when mated to Holsteins.

Substantial genetic differences across beef cattle breeds could impact commodity valuation. However, the influence of sire breed on the growth and carcass metrics of beef × dairy progeny is outdated such that relevance to current genetics may be limited (Pahnish et al., 1969; Southgate et al., 1982, 1988). Current data from other countries has supported differences by sire breed in growth rates and subsequent carcass weights and dressing percentages (Huuskonen et al., 2013; Rezagholivand et al., 2021). These data are hard to translate to the current U.S. beef production system due to genetic and management changes over time and different genetic lineages and selection parameters in international markets.

More relevant literature on the feedlot performance and carcass characteristics of beef × dairy progeny in the United States primarily compares the phenotypic performance of beef × dairy animals with that of native beef cattle and Holstein steers (Foraker et al., 2022a; Fuerniss et al., 2023). Jaborek et al. (2019) determined that Angus and SimAngus-sired cattle born to Jersey dams had 0.12 kg greater average daily gain (ADG) than Red Wagyu-sired cattle born to Jersey dams. In addition, they reported that Angus × Jersey cattle produced carcasses with greater marbling than Red Wagyu × Jersey cattle and SimAngus × Jersey cattle (Jaborek et al., 2019). Current published data examining beef × dairy progeny performance by sire breed is limited to calves born to Jersey dams.

Among the U.S. dairy herds that participate in Dairy Herd Information testing, about 80% of the cattle are Holstein, thus a greater proportion of the beef × dairy cattle in the U.S. are born to Holstein dams, not Jersey dams (CDCB, 2020). We hypothesized that rate of gain, feed efficiency, and carcass characteristics would vary by sire breed of beef × Holstein steers. Therefore, our objective was to compare the feedlot performance and carcass characteristics of beef × Holstein steers by beef sire breed when sires represented bulls with commercially available semen.

Materials and Methods

This research was approved by the Pennsylvania State University Institution Animal Care and Use Committee (Protocol # 202001343). A total of three groups of steers were finished over 3 yr for this study. Steer groups will be referred to by the year they were finished (2021, 2022, and 2023) where it is necessary to distinguish between them.

Sire Selection

Due to the timing of received funding (March 2020), the 2021 steers were sourced from Holstein herds in Pennsylvania that mated a portion of their cows to commercially available Angus and SimAngus semen in 2019 (Table 1). Therefore, sires of the 2021 steers represented beef × dairy selection criteria of the dairy producers and genetics companies at the time dairy dams were mated (2019). However, the steers fed in 2022 and 2023 resulted from planned matings to sires with available semen from Premier Select Sires in 2020 and 2021, respectively (Table 1). In 2020, Holstein cows were mated to Angus, SimAngus, Charolais, and Wagyu semen to generate the calves that were fed in 2022 and in 2021 Holsteins were mated to Angus, Red Angus, SimAngus, Simmental, Limousin, Charolais, and Hereford semen to generate the calves that were fed in 2023.

The bulls used for planned matings in 2020 and 2021 were chosen based on genetic merit for growth and carcass traits; the intention was to utilize bulls that ranked near the top of their respective breeds for terminal performance. However, sire selection was limited by both bull and semen availability. Given that only single-born bull calves were retained for this study, a minimum of 50 units of semen per sire were required to attempt to generate sufficient progeny. In 2022, only three Charolais bulls and two Wagyu bulls were available from the participating genetics company, due to the limited popularity of those breeds at the time. Similarly, limited Charolais and Limousin sires (five and four bulls, respectively) were available to select from when generating the 2023 calves. While using beef breeds with limited sire availability reduced the opportunity to select those sires based on genetic merit, the matings were representative of the same selection opportunities available to U.S. dairy farmers at the time. Both survey data and analyses of dairy herd records indicate that Wagyu, Limousin, and Charolais semen is being utilized in beef × dairy matings, despite the limited selection of commercially available semen from those breeds (Pereira et al., 2022; Felix et al., 2023; Lauber et al., 2023).

When semen was available from more than three bulls of the same breed, sires were selected based on their expected progeny differences (EPD) ranking for growth and carcass traits and terminal index values within their respective breeds. Traits with EPD available varied by sire breed; in the case of the two available Wagyu sires, EPD were not available until after the planned matings occurred as the American Wagyu Association first released EPD in 2021 (Rutherford, 2021). Yearling weight, carcass weight, ribeye area, and marbling score EPD were available for all other sire breeds, as was a terminal index value respective to individual breeds. The within-breed ranking of individual bulls for the aforementioned growth and carcass traits and terminal index values were considered during sire selection (Supplementary Table S1). It is important to note that, since the time of bull selection, EPD values and within-breed rankings have changed as additional progeny phenotypes are added to genetic evaluations, increasing EPD accuracy, and as younger animals with greater genetic merit are born in the population. Sire EPD values, accuracies, and ranking current to the preparation of this manuscript and EPD of growth and carcass traits specific to certain breeds are available in Supplementary Table S2 but were not available at the time of bull selection.

Sire breed was defined by National Association of Animal Breeders (NAAB) breed code; thus, the SimAngus-sired calves were grouped with the Simmental-sired calves fed in 2023. Breeding values of Simmental and SimAngus cattle are derived from the same population and grouping the sires better reflects the genetic population of registered Simmental cattle in the United States, as purebred Simmental (≥87.5% Simmental lineage by pedigree) cattle represent less than 1/3 of the breed's herd book (ASA, 2024). Additionally, recent evaluation of selection signatures in genotyped Simmental cattle suggests that, within both the purebred and registered Simmental-influenced cattle populations, Angus genetics have been incorporated to shift away from red, piebald coat coloration to solid black coat coloration (Rowan et al., 2024).

Calf Acquisition and Preweaning Management

The steer group fed in 2021 was comprised of single-born, male calves (*n* = 32), born between May and August of 2020 to Holstein dams, sourced from five dairy herds in Pennsylvania. Calves received colostrum on the dairy and, within 2 wk of birth, were transported to a commercial preweaned calf grower. At the calf grower, management protocols, including feeding and vaccinations, were identical among all calves. Postweaning health issues in the calves fed in 2021 resulted in the research team designing new vaccination protocols for calves in future years, outlined below. Calves were castrated at approximately 5 wk of age and remained with the grower through weaning.

Planned matings that resulted in the conception of the steers fed 2022 occurred on seven Pennsylvania dairies in 2020. Only two of the dairies that provided 2021 steers participated in planned matings to produce 2022 steers. The 2022 steer group was comprised of single-born, male calves (*n* = 127) born from May 1, 2021 to August 1, 2021. Likewise, the planned matings that resulted in the conception of the 2023 steers occurred in 2021 on five of the Pennsylvania dairies that previously produced steers for the 2022 group. Single-born, male calves (*n* = 103) born from April 8, 2022 to July 1, 2022 were retained for the project. The quantity of semen units available for planned matings varied by individual bull. Not every participating herd used every bull or breed examined; some farms were reluctant to use certain breeds due to concerns related to dystocia risk while others were unwilling to use Charolais because the calves that were not enrolled in the study (heifers and twins) were perceived to have reduced value with colored hides. Furthermore, conception rates, sex ratio, and the number of cows available for insemination during the breeding window varied by herd size, thus the quantity of calves from each herd varied.

At birth, 2022 and 2023 calves were fed 4 L of colostrum (≥50 mg IgG/mL) and tagged with a unique ID. Within 7 d of birth, 2022 calves were transported to one of the two commercial calf grower facilities located in Belleville, PA and Reedsville, PA, and 2023 calves were transported to one of the two commercial calf grower facilities located in Belleville, PA and Willow Hill, PA. On arrival at the calf grower, calves were immunized intranasally with INFORCE 3 (Zoetis Inc., Parsippany, NJ). Calves in the Belleville and Willow Hill facilities were individually housed until weaning while calves in the Reedsville facility were housed in groups of four to five. Calves were fed a commercial milk replacer and had free access to water and textured starter grain. At 5 ± 2 wk of age calves were surgically castrated. Calves were vaccinated with a second dose of INFORCE three approximately 6 wk following the initial vaccine.

Postweaning Management

The 2021 calves were weaned at 6 ± 2 wk of age and moved to a bedded-pack feedlot facility in Reedsville, PA. At 3 ± 1 mo of age steers were implanted with Synovex-C (100 mg progesterone, 10 mg estradiol benzoate; Zoetis Inc., Parsippany, NJ). Steers were implanted with a second Synovex-C at 7 ± 1.5 mo of age.

At 8 ± 1 wk old, 2022 and 2023 calves were weaned and moved to the bedded-pack pen at the Reedsville facility. Between 3 and 4 mo of age, steers were vaccinated with Alpha-7 (Boehringer Ingelheim, Ingelheim, Germany) and BOVI-SHEILD GOLD 5 (Zoetis Inc., Parsippany, NJ). Due to supply chain issues, the youngest group of 2022 steers were vaccinated with BOVILIS Vision 7 with SPUR (Merck Animal Health, Rahway, NJ) rather than Alpha-7. Those calves received a second dose of BOVILIS Vision 7 with SPUR 4 wk following their first dose. Following Alpha-7 and BOVI-SHIELD GOLD 5 vaccination, calves were moved to a second bedded-pack facility. Steers were implanted with Synovex-C at 5 ± 1 mo of age. The 2023 steers were given a second dose of BOVI-SHEILD GOLD 5 at the same time. At 8.5 ± 1 mo of age, steers received a Synovex-S implant (200 mg progesterone, 20 mg estradiol benzoate; Zoetis Inc., Parsippany, NJ) and 2022 steers received a second dose of BOVI-SHEILD GOLD 5.

All three groups of steers were fed corn grain, pelleted grain, and free choice hay until they were approximately 6 ± 2 mo old; they were then transitioned to a corn silage-based TMR that provided about 1.36 Mcal/kg NE_g. Blood or tail hair with roots were sampled from all cattle so that sire identification could be verified by genotype. Calf DNA was extracted from tissue samples and sequenced with the Igenity Beef chip (42k SNP; Neogen Corporation, Langsing, MI).

Feedlot Management

In April of each year, steers were transported to the Pennsylvania Department of Agriculture Livestock

Table 2. Composition of finishing diet fed to beef × Holstein steers by year on feed.

Item	Year on feed		
	2021	2022	2023
Ingredient (% dry matter basis)			
Corn silage	20.00	17.00	17.25
Cracked corn	64.50	67.50	67.50
Soybean meal	6.50	6.50	6.50
Dried distillers grains with solubles	6.50	6.50	6.50
Mineral mix[1]	1.50	1.50	1.50
Limestone	1.00	1.00	0.75
Analyzed nutrient composition			
DM, %	70.0	76.7	75.9
CP, % DM basis	13.2	12.9	12.8
NDF, % DM basis	17.4	15.7	17.5

[1] Mineral and vitamin supplement = 1,550 g/ton Rumensin 90 (198 g of monensin/kg of DM; Elanco Animal Health, Greenfield, IN), Ca 25%, NaCl 15%, Mg 1%, K 3.5%, Zn 1,000 mg/kg, Cu 180 mg/kg, Se 16 mg/kg, Vit A 130,000 IU/lb (Agri-Basics, Inc.; Elizabethtown, PA).

Evaluation Center (LEC) in Pennsylvania Furnace, PA. At arrival to the LEC, the 2021 group of steers were 9.5 ± 1.5 mo old, the 2022 steers were 10 ± 1 mo old, and the 2023 steers were 11 ± 1 mo old. The LEC feedlot consists of a gable roof confinement barn with interior pens, constructed of metal gates and cables, on concrete floor (30.5 × 7.5 m) that opens on the back side to an exterior gravel lot (30.5 × 61 m).

Once steers transitioned to the feedlot diet (Table 2), data collection began (day 0). Steers were tagged with electronic identification tags (EID; Allflex Half Duplex, Merck Animal Health, Rahway, NJ). In 2021, steers were implanted on day 0 with Revalor XS (200 mg trenbolone acetate, 40 mg estradiol; Merck Animal Health, Rahway, NJ). In 2022 steers were implanted on day 29 with Revalor S (120 mg trenbolone acetate, 24 mg estradiol; Merck Animal Health, Rahway, NJ). In 2023, steers were implanted on day 0 with Synovex One Grower (150 mg trenbolone acetate; 21 mg estradiol benzoate; Zoetis Inc., Parsippany, NJ). Implant protocol varies year to year due to implant availability.

Steers were acclimated to the feedlot diet in multiple steps where each step increased concentrate and decreased forage. The 2021 steers were acclimated using two diet steps over 7 d, 2022 steers were acclimated using three diet steps over 14 d, and 2023 steers were acclimated using two diet steps over 8 d. The feedlot diet was fed for ad libitum feed intakes. Individual feedstuffs were sampled approximately every 30 d for the duration of the trial. Samples were used to determine dry matter and adjust inclusion of dietary ingredients. Additionally, 500 g subsamples were composited and frozen at −20 °C. At the completion of the trial, composited feed samples were analyzed using wet chemistry methods for dry matter, neutral detergent fiber, acid detergent fiber, crude protein, ether extractable fat, Ca, and P by a commercial laboratory (Cumberland Valley Analytical Services, Waynesboro, PA).

Feedlot Data Collection

Once acclimated to the final diet, initial body weights were determined by averaging body weights taken on days 0 and 1. Individual feed intakes were monitored using the GrowSafe Feed Intake System (Model 4,000E; Vytelle, LLC., Lenexa, KS); individual steer intakes were considered acceptable if both 85% of the feed supplied and 90% of the feed that disappeared from the bunk could be attributed to cattle assigned within the pen. Two individuals (1 Red Angus-sired, 1 Simmental-sired) had fewer than 42 d of acceptable feed intakes, thus were excluded from analyses related to feed intake.

Final body weights were determined by averaging two consecutive weights taken in the last 2 d of the test and applying a 2.5% shrink. Hip height was also measured on final day of test. Steers were restrained in a chute and hip height was determined with vertical measuring stick fitted with a crossbar and level. One Red Angus-sired steer evaded hip height measurement, thus was excluded from the hip height analysis.

In 2021, due to the limited number of cattle, all steers were shipped to slaughter on d151. In 2022 and 2023, steers were shipped in slaughter groups on days 90, 118, 153, 110, 131, and 152, respectively. Slaughter groups were based on body weight; however, due to facility restrictions, all remaining cattle were slaughtered by the last date of each year regardless of body weight. Steers were transported 312 km to a commercial beef processing facility and slaughtered according to the Humane Slaughter Act.

ADG was calculated as the difference between final body weight and initial body weight divided by days on feed. Dry matter intake (DMI) was calculated as the mean of acceptable as-fed intakes, as monitored by Growsafe, multiplied by diet dry matter. Gain:feed is reported as the ratio of ADG:DMI.

Carcass Data Collection

Both sides of each carcass were weighed after slaughter, following halving and removal of the hide, head, and organs to determine hot carcass weight (HCW). Kidney, pelvic, and heart fat (KPH) was removed prior to weighing; therefore, HCW was calculated as the sum of the weights of both carcass sides with a standard 2.5% KPH added back. Dressing percentage was calculated as HCW divided by feedlot final body weight.

Three days following slaughter, trained research personnel evaluated the chilled right side of carcasses at the 12th rib for back fat width (BF), ribeye area (REA), and USDA marbling score. yield grade (YG) was calculated using the USDA YG equation (USDA, 2017) with 2.5% estimated as KPH across all carcasses. One carcass from a Charolais-sired steer was misplaced prior to evaluation by research personnel. A second carcass from a Charolais-sired steer did not have BF measured. Thus, there were 261 REA measurements and marbling scores and 260 BF measurements and YG.

A section of the longissimus muscle (LM), from the 10th to 12th rib, was cut from each carcass and transported to the Pennsylvania State University Meat Science Laboratory for tenderness and intramuscular fat (IMF) evaluation. Rib sections were refrigerated at 3 °C for about 12 h, then vacuum sealed and frozen at −20 °C. Four rib sections, including the section from the missing Charolais carcass, were not removed from the plant (1 Angus-sired, 1 Charolais-sired, 1 Wagyu-sired, and 1 Simmental-sired) thus, 258 samples were evaluated for tenderness and IMF.

Tenderness and Intramuscular Fat Evaluation

Rib sections were thawed at 3 °C for approximately 48 h. Two 2.54 cm steaks were cut from the 12th rib end to be evaluated for tenderness using Warner-Bratzler Shear Force

(WBSF). Samples were cooked and evaluated per American Meat Science Association Guidelines (AMSA, 2016). K-type thermocouple probes attached to a SR630 16-channel Thermocouple Monitor (Stanford Research Systems, Sunnyvale, CA) were inserted into the approximate geometric center of each steak to monitor cooking temperature. Steaks were roasted in an oven at 163 °C. Oven temperature was monitored by thermocouple and adjusted as needed to account for temperature changes when samples were inserted or removed. Samples were removed from the oven at 69 °C and rose to a peak internal temperature of 71 °C. Steaks were then chilled at 3 °C overnight. A total of six 1.27 cm round cores were taken from each steak parallel to the direction of the muscle fibers. Cores were sheared perpendicular to muscle fibers using a TMS-Pro Texture Analyzer (PPT Group UK Ltd, Slinfold, West Sussex, United Kingdom) fitted with a V-notch Warner-Bratzler shear blade (crosshead speed 240 mm/minute). Peak force was recorded for each core; force values were averaged for a total of 12 cores from duplicated steaks.

An additional 2.54 cm steak was cut from each rib section to measure LM IMF. All subcutaneous fat was trimmed and the remaining muscle tissue and IMF were cubed and ground in a food processor (Model: 72500PS; Hamilton Beach, Glen Allen, VA) and frozen at -20°C until analysis. Ground samples were thawed at 3 °C for 12 h. Longissimus muscle IMF was extracted from the ground sample using petroleum ether (Ankom Method 2; Seenger et al., 2008).

Statistical Analysis

Feedlot performance traits and carcass characteristics were fit by linear mixed models in the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). All models included random effects of individual sire, year on feed (2021, 2022, or 2023), and dairy herd of origin (herds one to six). While calves were sourced from 10 different dairies, five of the dairies had <10 beef × Holstein steers on the study and were subsequently collated into one 'other' herd. Including herd of origin as a random effect accounted for variation that could have been caused by maternal environment and early life environment. By including year-on feed in the models, we accounted for some of the variation, including implant protocols, that could not be controlled between years. Sire breed was a fixed effect. Significant differences are discussed at $P < 0.05$.

Results and Discussion

Feedlot Performance

Gain and intake. There were no differences in initial or final steer body weight by sire breed ($P > 0.05$; Table 3). All steers were selected for slaughter based on body weight; therefore, the lack of difference in final body weight is expected. In contrast, when Jaborek et al. (2019) fed Angus, SimAngus, and Red Wagyu-sired beef × Jersey cattle, Angus and SimAngus-sired animals finished at a heavier body weight (510 kg) than Red Wagyu-sired animals (485 kg), despite researchers' efforts to maintain similar final body weights.

Despite the similar initial and final body weights of beef × Holsteins steers across sire breeds, steer sire breed impacted ADG (Table 3; $P < 0.01$). Wagyu × Holstein steers gained the least (1.39 kg/d; $P < 0.05$), but did not differ from that of Limousin-sired steers. Angus × Holstein steers had the greatest ADG (1.76 kg/d), but the ADG of Angus × Holstein steers did not differ from Charolais, Hereford, or Simmental-sired steers. Because of the differences in ADG, days on feed varied by sire breed. Wagyu × Holstein steers had 5, 19, 24, and 26 more ($P < 0.05$) days on feed than Limousin × Holstein, Simmental × Holstein, Angus × Holstein steers, and Charolais × Holstein, respectively. Angus and Charolais-sired steers were on feed for 19 and 21 d fewer, respectively, than Limousin-sired steers ($P < 0.05$).

Similar differences in ADG by sire breed have previously been reported in fed beef × Jersey cattle. Angus and SimAngus-sired beef × Jersey cattle gained 0.12 kg more per day than Red Wagyu × Jersey animals (Jaborek et al., 2019). In the same study, Red Wagyu × Jersey animals were on feed for 34 d more than Angus × Jersey cattle and 23 d more than SimAngus × Jersey cattle (Jaborek et al., 2019). In contrast to our results, Rezagholivand et al. (2021) did not report differences in ADG between Angus, Charolais, and Limousin-sired cattle born to Holstein dams. Rezagholivand et al. (2021) conducted their work in Iran and reported management practices differed from the present study. In addition, Rezagholivand et al. (2021) fed both steers and heifers and did not implant the cattle. Therefore, differences in sex and management may have restricted breed differences from being expressed. In the present study, the differences observed for steer DMI were similar to those in ADG (Table 3; $P < 0.01$). The steers that consumed less feed gained less

Table 3. Feedlot performance of beef × Holstein steers by beef sire breed.

	Sire breed								
Trait	AN	AR	CH	HP	KB	LM	SM	SE	*P*-value
n steers (*n* sires)[1]	47 (10)	28 (2)	92 (5)	19 (2)	11 (2)	18 (2)	47 (6)	—	—
Initial body weight, kg	396	389	399	386	355	367	404	53	0.67
Final body weight[2], kg	634	619	629	620	583	609	641	46	0.20
Average daily gain, kg/d	1.76^{a}	1.62^{bc}	1.73^{ab}	1.66^{abc}	1.39^{d}	1.55^{cd}	1.68^{ab}	0.09	<0.01
Dry matter intake, kg/d	14.3^{a}	13.9^{ab}	14.0^{a}	13.8^{ab}	12.0^{c}	13.0^{bc}	14.0^{a}	0.7	<0.01
Gain to feed, kg/kg	0.124	0.115	0.124	0.119	0.119	0.118	0.119	0.005	0.44
Days on feed	133^{c}	138^{abc}	131^{c}	138^{abc}	157^{a}	152^{b}	138^{bc}	10	0.01
Hip height, cm	139	137	139	137	139	137	140	3	0.47

[1] Dry matter intake and gain to feed had 27 AR and 46 SM observations; hip height had 27 AR observations due to a missing measurement.

[2] A 2.5% shrink was applied to final body weight.

[a,b,c,d] Values within row with different superscript are different at $P < 0.05$.

AN, Angus; AR, Red Angus; CH, Charolais; HP, Hereford; KB, Wagyu; LM, Limousin; SM, Simmental or SimAngus.

weight; therefore, no differences in the ratio of gain:feed existed between sire breeds. Jaborek et al. (2019) observed a similar pattern; Angus × Jersey and SimAngus × Jersey cattle ate more than Red Wagyu × Jersey, though ultimately feed conversion rates did not differ between sire breeds.

Of particular note are the deficiencies of the Waygu-sired steers in this study. Similar reductions in growth have been observed in Wagyu-sired progeny born to both native beef and dairy dams (Radunz et al., 2009; Jaborek et al., 2019). However, in the present work, Limousin-sired steers had similar growth performance to Waygu-sired steers. Less data exists to corroborate the differences observed in the Limousin-sired steers. At the time of sire selection, the two Limousin bulls used ranked within the top 3% and 30% of the breed for their yearling weight EPD values (Supplementary Table S1). Since then, substantial reranking has occurred, placing the bulls in the 70th and 80th percentile for yearling weight EPD (Supplementary Table S2). While EPD were not available at the time of selection of the Wagyu sires, current EPD ranks the two bulls in the 20th and 55th percentile of the breed for yearling weight (Supplementary Table S2). Sires of other breeds have also reranked within breed for yearling weight EPD since the time of selection; for example, the SimAngus sires used to generate the 2022 steers were in the 15th and 25th percentile for yearling weight EPD at the time of selection but have since reranked to the 55th and 65th percentile, respectively (Supplementary Table S1 and S2). However, among the sires of the 2023 steers only the Limousin bulls currently rank greater than the 50th percentile in yearling weight EPD (Supplementary Table S2). More data from Limousin × Holstein progeny from sires that rank well for yearling weight within the breed are required to validate the differences observed in ADG.

Angus × Holstein steers had similar growth performance to Charolais × Holstein and Simmental × Holstein steers in this study. Historic data from North America, and more current data collected internationally, report that Charolais × dairy cattle are younger at slaughter and have greater ADG than Angus and Hereford-sired progeny born to dairy breed dams (Pahnish et al., 1969, 1971; Urick et al., 1974; Fahmy and Lalande, 1975; Huuskonenen et al., 2013). We hypothesize that the similarities in growth performance between Angus and Charolais-sired beef × dairy progeny presented here exemplify a recent shift in beef breed genetics in the United States. Selection within the Angus breed has resulted in enhanced growth in the breed such that, among breeds evaluated by the U.S. Meat Animal Research Center, Angus now have the greatest average yearling weight and mature body weight (Zimmermann et al., 2021; Kuehn and Thallman, 2023). The ability of the Angus × Holstein steers to maintain equivalent ADG to those sired by Simmental and Charolais-sired steers demonstrates this effective shift in the U.S. Angus population toward terminal production in recent years (Zimmermann et al., 2021). The large population of registered Angus cattle in the United States has likely contributed to its success and ability to make genetic progress. The American Angus Association is the largest beef breed association in the country (American Angus Association, 2023). It is estimated that 60% of fed cattle have Angus genetic influence (Drouillard, 2018); that proportion is likely greater as beef × dairy animals have replaced fed Holsteins. The Angus breed has topped domestic beef semen sales since the earliest NAAB semen sales report in 1979; since 2019, Angus has ranked second in all cattle semen sales, behind Holstein, due to the increase in beef × dairy matings (NAAB, 2023). When compared with previous growth performance data of beef × dairy cattle, the presented data suggests that selection trends within the Angus breed are being realized in beef × dairy progeny as we select beef sires to use in dairy herds.

Hip height. Hip height at slaughter did not differ by steer sire breed (Table 3; $P > 0.05$). The selection index designed by the American Angus Association for Angus × Holstein matings has a negative emphasis on yearling height to mitigate problems associated with increased frame size due to Holstein genetics (Miller et al., 2021). While some of the Angus sires used in this experiment were selected based on ranking on the Angus × Holstein index, the negative emphasis on yearling height did not create beef × Holstein progeny any shorter than those sired by other beef breeds that do not have selection parameters related to frame size.

Previous work has suggested that the frames of beef × Holstein progeny are not as large as those of purebred Holsteins. One study reported that Holstein bulls were 8 cm taller at the hip and subsequently had carcasses that were 7 cm longer than Charolais × Holstein-Friesian bulls (McGee et al., 2007). Other authors have used back length, instead of hip height, as a means of reporting frame size. These authors stated that, prior to slaughter, the length of the backs of Simmental, Limousin, Angus, and Charolais-sired beef × Holstein cattle were 1 to 4 cm shorter than Holsteins finished in the same conditions (Forrest, 1980, 1981; Rezagholivand et al., 2021). The average hip heights of steers in this study (137 to 140 cm) were similar to that of the beef × Holstein cattle in the Iranian study (137 to 139 cm; Rezagholivand et al., 2021). In that study, Holsteins were taller, at 145 cm (Rezagholivand et al., 2021). While the data presented here suggests that beef × Holstein progeny are similar in hip height regardless of sire breed, additional studies are needed to validate these findings. These data will be particularly important if the industry chooses to devalue available beef sires on the basis of yearling height.

Carcass characteristics. No differences by sire breed were observed in HCW and dressing percentage of carcasses from beef × Holstein steers (Table 4; $P > 0.05$). This is likely reflective of the target final body weight used for the steers in this study. Though not statistically significant, Wagyu × Holstein carcasses were 37 kg lighter than those from Angus and Simmental-sired beef × dairy steers while dressing percentage remained similar among the breeds. Research evaluating beef × Jersey animals reported that the carcasses of Red Wagyu-sired cattle were about 20 kg lighter than the carcasses of SimAngus and Angus-sired cattle; dressing percentage was also similar by sire breed (Jaborek et al., 2019). Despite these differences in HCW, there were no differences in red meat yield between Angus × Jersey, SimAngus × Jersey, and Red Wagyu × Jersey carcasses (Jaborek et al., 2019). Similar to the data presented here, Jaborek et al. (2019) slaughtered cattle at a target end weight, but time limitations prevented all cattle from reaching the target weight by the final slaughter date.

The dressing percentages of carcasses in this study ranged from about 60% to 62%. These dressing percentages are less than the average native beef cattle dressing percentage of 63% nationwide (USDA, 2023), and are less than what other researchers have observed in beef × dairy animals. Work by

Foraker et al. (2022a) observed that native beef animals averaged a 64.2% dressing percentage while beef × dairy cattle on the same feedlot dressed 63.2%. Still, the dressing percentage of our beef × dairy animals was markedly improved from that of purebred Holsteins steers previously fed, managed, and slaughtered in the same facilities; just below 59% (Carvalho et al., 2020). A challenge in interpreting dressing percentage data from this study is that the meatpacking plant removed KPH prior to the HCW being recorded. Therefore, 2.5% KPH is assumed on all carcasses for the purposes of calculating dressing percentage. However, this assumption limits true interpretation of differences that may exist due to KPH.

Ribeye area and BF thickness did not differ by sire breed (Table 4; $P > 0.05$). Results are similar to older work that compared Angus, Hereford, and Charolais-sired cattle born to Brown Swiss dams determined there were no differences in REA nor backfat thickness (Urick et al., 1974). After adjusting carcass parameters to a common carcass weight, Jaborek et al. (2019) did not observe differences in REA between sire breeds of beef × Jersey carcasses; however, the backfat of Angus × Jersey was 0.30 cm thicker than that of SimAngus × Jersey carcasses and 0.36 cm thicker than that of Red Wagyu × Jersey carcass (Jaborek et al., 2019).

Because HCW, REA, and BF are all metrics used to calculate USDA YG, the lack of differences in those parameters by sire breed resulted in no differences in average calculated YG (Table 4; $P > 0.05$). Previous research observed no differences in calculated yield between Angus, SimAngus, and Red Wagyu-sired beef × Jersey carcasses (Jaborek et al., 2019). However, the beef × Jersey carcasses averaged a calculated YG4 (Jaborek et al., 2019), while the beef × Holstein carcasses in our study averaged YG2 or YG3.

Though proportion of IMF did not differ by sire breed when measured chemically, the more economically relevant trait of USDA marbling score, determined by visual assessment, did (Table 4; $P = 0.03$). Red Angus × Holstein carcasses, on average, achieved marbling scores equating to Modest (5.03), equivalent to a USDA Quality Grade of Average Choice. The average marbling score of steers sired by other sire breeds was equivalent to a USDA Quality Grade of Low Choice (4.14 to 4.82).

The Angus × Jersey cattle in the trial conducted by Jaborek et al. (2019) achieved an average marbling score equivalent to the USDA Quality Grade of Average Prime, which exceeded the quality grades of Red Wagyu × Jersey and SimAngus × Jersey carcasses that had average marbling scores equivalent to High Choice. Foraker et al. (2022a) reported an average marbling score of beef × dairy carcasses determined by video image analysis to 4.8, which is more in-line with the range of scores observed across sire breeds in this study. In the Foraker et al. (2022a) study, native beef cattle had lower marbling scores than beef × dairy cattle, of just 4.5, and only 53% of native beef carcasses graded Choice or Prime while 78% of beef × dairy carcasses were Choice or greater (Foraker et al., 2022a). In this study, regardless of statistical differences, all sire breeds resulted in beef × Holstein progeny that averaged Choice. The data presented here agrees with the limited literature that suggests that beef × dairy carcasses, like dairy-type carcasses, have a desirable quantity of marbling, when fed and managed in intensive systems.

Greater force was required to shear the LM from Simmental-sired steers (4.51 kg) than those LM samples from Limousin (3.70 kg), Hereford (3.83 kg), and Angus-sired steers (3.82 kg; Table 4; $P = 0.04$). The LM from Angus-sired steers required less force than those from Charolais-sired steers to shear. In previous literature, beef from SimAngus × Jersey (2.45 kg) and Red Wagyu × Jersey (2.34 kg) steers was more tender than beef from Angus × Jersey (2.69 kg; Jaborek et al., 2019). Despite the differences in tenderness between sire breeds in the beef × Jersey cattle, the average WBSF of LM from all sire breeds would qualify as Certified Very Tender (ASTM, 2018; Jaborek et al., 2019). Further, differences less than 0.5 kg of force are not considered detectable by consumers (Miller et al., 1995). In our study, while variation beyond

Table 4. Carcass characteristics of beef × Holstein steers by beef sire breed.

	Sire breed								
Trait	AN	AR	CH	HP	KB	LM	SM	SE	*P*-value
n steers (*n* sires)[1]	47 (10)	28 (2)	92 (5)	19 (2)	11 (2)	18 (2)	47 (6)	—	—
Dressing percentage[2], %	61.7	61.9	60.7	60.2	61.1	61.0	61.4	1.0	0.19
Hot carcass weight[3], kg	392	382	381	371	355	369	392	33	0.19
Back fat, cm	0.94	1.18	0.89	1.03	0.63	1.01	0.97	0.20	0.18
Ribeye area, cm^2	85.0	82.8	82.0	78.8	80.7	82.3	82.3	3.8	0.56
Calculated yield grade[4]	2.94	3.25	3.00	3.23	2.55	3.02	3.14	0.41	0.65
Marbling score[5]	4.82^{ab}	5.03^{a}	4.71^{ab}	4.61^{abc}	4.59^{abc}	4.14^{c}	4.50^{bc}	0.47	0.03
Intramuscular fat, %	4.94	5.38	4.31	5.23	4.16	4.24	4.37	0.80	0.67
Warner-Bratzler shear force[6], kg	3.82^{c}	4.14^{abc}	4.30^{ab}	3.83^{bc}	3.93^{abc}	3.70^{bc}	4.51^{a}	0.41	0.04

[1] Ribeye area and marbling score had 91 CH observations; backfat and yield Grade had 90 CH observations; intramuscular fat and Warner-Bratzler shear force had 46 AN observations, 91 CH observations, 10 KB observations, and 46 SM observations.
[2] Calulated as hot carcass weight/final body weight × 100%.
[3] 2.5% was added to account for removal of kidneys, pelvic fat, and heart prior to weighing.
[4] Carcass yield grade calculated using the study by USDA (2017) Yield Grade equation.
[5] Numeric marbling scores range from 1.0 to 9.9 where a score of 4.0 = Small^{00}, a score of 5.0 = Modest^{00}, etc.
[6] A Warner-Bratzler shear force value ≤ 4.40 kg qualifies as USDA Certified Tender; a Warner-Bratzler shear force value ≤ 3.90 kg qualifies as USDA Very Certified Tender.
[a,b,c] Values within row with different superscript are different at $P < 0.05$.
AN, Angus; AR, Red Angus; CH, Charolais; HP, Hereford; KB, Wagyu; LM, Limousin; SM, Simmental or SimAngus.

0.5 kg existed in WBSF between sire breeds, only steaks from Simmental-sired steers did not qualify as USDA Certified Tender or USDA Certified Very Tender (ASTM, 2018).

The American Simmental Association is the only U.S. breed association among the beef breeds investigated that provides EPD for shear force. With the exception of 7SM107, all of the Simmental and SimAngus sires represented in this study rank within the top 15% of sires evaluated by the breed association for shear force. To ensure that progeny of 7SM107 were not negatively biasing the overall WBSF estimates for Simmental progeny on this study, the seven progeny were removed from the data set and the same analysis was run. When the progeny of 7SM107 were removed, results were unchanged for the WBSF model. This, in part, may be due to the low accuracy of WBSF EPDs due to few phenotypes. Tenderness testing can be time-intensive and is not a phenotype that is collected during commercial carcass fabrication. Our results suggest that, despite the breed placing selection pressure on tenderness, Simmental and SimAngus-sired beef × Holstein progeny may not produce steaks as tender as those from Angus and Limousin progeny born to Holstein dams. Greater genetic improvement could be made in tenderness if resources are put into collecting more WBSF phenotypes.

Regardless of breed, the demand from dairy herds for beef semen represents a unique opportunity for genetics companies and seedstock producers to collaborate in producing beef bulls with high terminal breeding values, not just improved WBSF. The potential traceability of beef × dairy progeny has been discussed as an attribute for beef marketing by Foraker et al. (2022b). Traceability of beef × dairy progeny could also allow breed associations to develop pipelines for terminal phenotypes of beef × dairy progeny to improve genetic evaluations. Ultimately, affordable, quality terminal beef genetics are required for beef × dairy animals to meet market needs.

Without traceability currently in place, industry-wide data collection on beef × dairy crosses may be challenging. Many of these calves look, phenotypically, like beef cattle. Perhaps reassuringly, the data presented herein suggest that regardless of sire breed, beef × Holstein progeny from bulls that ranked within the top of their respective breeds for growth and carcass traits produced quality carcasses that met expectations of the U.S. meatpacker. These preliminary data suggest that, when appropriate bull selection standards are applied and progeny are grown and managed similarly, breed had relatively little influence on feedlot growth performance and carcass outcomes. While the data presented here suggests that Wagyu and Limousin sires with semen readily available for beef × dairy matings may produce beef × Holstein progeny that grow more slowly than those sired by other beef breeds, limited sire availability likely factored into these findings. Additional data collection should be attempted on a larger industry-wide scale to corroborate these findings.

Supplementary Data

Supplementary data are available at *Translational Animal Science* online.

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Conflict of interest statement

The authors declare no conflicts of interest.

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