Meat Science 201 (2023) 109178

Contents lists available at ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Growth, carcass and meat quality characteristics of Charolais-sired steers and heifers born to Angus-cross-dairy and Angus breeding cows

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A R T I C L E I N F O

Keywords:
Beef
Meat
Quality
Breed
Dairy
Carcass
Sex
Beef-on-dairy

A B S T R A C T

Charolais-sired heifers and steers from Angus, Angus × Holstein-Friesian, Angus × Holstein-Friesian-Jersey and Angus × Jersey cows were measured for growth, carcass, and meat quality characteristics. Despite differences in weaning weight and growth rate, the progeny of different breed-crosses did not differ in final live weight or carcass weight ($P > 0.05$). Carcass and meat quality characteristics did not differ among breed-crosses ($P > 0.05$), except for fat that was more yellow in progeny from Angus and Angus-cross-Jersey dams. Steers were slaughtered older and had heavier carcasses with greater fat depth and intramuscular fat than heifers. Meat quality differed between the sex classes, with steers having greater pH and shear force, redder meat, and yellower fat than heifers. Angus-cross-dairy cows when crossed with a beef breed sire such as the Charolais will provide progeny for meat production which are competitive to beef breeds for beef finishing and meat production and therefore, a useful mechanism to utilize surplus animals from the dairy industry.

1. Introduction

For cattle destined for beef production faster growth is associated with less time on-farm and reduced costs of feeding. Faster growth rates are considered a trait of beef breeds, however, crossbreeding of beef and dairy breeds, for use as beef breeding cows, takes advantage of desirable maternal traits from the dairy breeds for raising calves to a heavier weaning weight and also allows for heterosis effects on growth (Barton, Donaldson, Barnes, Jones, & Clifford, 1994; Hickson, Lopez-Villalobos, Kenyon, & Morris, 2014). The New Zealand dairy herd is primarily made up of Holstein-Friesian-Jersey cross (49.1%), Holstein-Friesian (32.7%) and Jersey (8.4%) cows (Dairy NZ, 2020). These cow types have different mature live weight, with Holstein-Friesian cows heavier than Jersey cows which has an impact on the growth potential of crossbred offspring for beef production (Burke, Purchas, & Morris, 1998; Handcock et al., 2018).

Angus-cross-dairy cows perform well as a beef breeding cow, utilising increased milk production abilities of the dairy breed to produce heavier calves at weaning (Hickson et al., 2014; Law, Hickson, Lopez-Villalobos, Kenyon, & Morris, 2013; Roca Fraga, Hickson, Lopez-Villalobos, Kenyon, & Morris, 2013; Vazquez et al., 2013). A key advantage of beef-cross-dairy cows as a beef breeding cow is the ready source of replacement heifers from the dairy industry, allowing all cows to be bred to terminal sires, for example, Charolais. This allows bulls to be selected purely on the expected finishing performance of their progeny, without making compromises for maternal traits as no daughters will be retained for breeding. The use of terminal sires also means that the heifers born in the herd are reared for processing, so it is important to consider the performance of heifer calves born to these cow types.

Heifers have slower growth rates and lower lean meat yields compared with steers and bulls of similar carcass weights (Bures & Barton, 2012; Lage et al., 2012; Wilson, Ziegler, Watkins, Thompson, & Purdy, 1969). Due to earlier far deposition in heifers, they tend to be slaughtered at younger ages and at lighter weights than steers to meet carcass grading requirements (Purchas, 2003), however, understanding the impact that the inclusion of dairy genetics has on this growth and carcass development is important for understanding the practical use of cattle from the dairy industry for beef production.

Heifers have been associated with more tender meat than that of steers due to the younger age at slaughter (Bures & Barton, 2012; Chambaz, Scheeder, Kreuzer, & Dufey, 2003; Koch et al., 1976; Lucero-

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https://doi.org/10.1016/j.meatsci.2023.109178
Received 18 July 2022; Received in revised form 22 March 2023; Accepted 30 March 2023
Available online 1 April 2023

Borja et al., 2014; Morgan & Everitt, 1969; Muir, Wallace, Dobbie, & Bown, 2000; Purchas, 1989; Seideman, Cross, Smith, & Durland, 1984). It is important to validate these meat quality characteristics of beef from heifers, compared to steers, with the inclusion of dairy genetics in the breed mix.

The aim of this experiment was to evaluate the carcass characteristics and meat quality of heifers and steers born to Angus-cross dairy (either Holstein-Friesian, Holstein-Friesian x Jersey, or Jersey) or Angus cows, sired by Charolais bulls when processed at a commercially relevant carcass weight for each sex.

2. Materials and methods

2.1. Animal resources and slaughter

This experiment was conducted with approval from the Massey University Animal Ethics Committee (MUAEC 09/21 and 12/27). One hundred and three crossbred steers and heifers born in the spring of 2012, were used in this experiment. They were sired by Charolais (C) bulls ($n = 4$). Charolais sires are a popular terminal sire in New Zealand and are a late-maturing beef breed. The Charolais bulls used in the experiment were appropriate terminal sires selected for high growth potential.

The dams were multiparous, four-year-old cows of four breed types: straight-bred Angus (AA, $n = 33$), Angus × Holstein-Friesian (AF, $n = 22$), Angus × Holstein-Friesian-Jersey cross (AK, $n = 16$) and Angus × Jersey (AJ, $n = 32$), sired by Angus bulls (n = 4) (Hickson et al., 2014). The Angus breed was chosen as the sire of the cows used in this study as it represents a breed used in the New Zealand dairy industry for natural mating to produce crossbred calves and is the predominant breed for beef cows in New Zealand, The Angus bulls were selected for short gestation length and low birthweight breeding values (Hickson et al., 2014). Maternal dams were commercially sourced, and maternal grand sires were representative of the New Zealand dairy herd (Friesian, Jersey, Holstein-Friesian-Jersey cross) and commercial beef herds (Angus) (Hickson et al., 2014).

Calves were reared on their dams in a single herd until a mean age of 193 days (heifers: 195 days, SD = 13.6 days; steers: 190 days, SD = 17.0 days; C-AA: 191 days, SD = 12.3 days; C-AF: 195 days, SD = 12.6 days; C-AK: 190 days, SD = 13.3 days; AJ-C: 194 days, SD = 19.1 days). Male calves were castrated using rubber rings at approximately 6 weeks of age. After weaning, the steers and heifers were managed as a single group rotationally grazing on pasture (predominately *Lolium perenne*) at Massey University's Tuapaka farm 15 km east of Palmerston North, New Zealand. At 324-days of age (August 2013) the cattle were split into a single steer and single heifer group until slaughter.

Heifers were slaughtered in a single group at a mean age of 574 days (May 2014) and steers in a separate group at a mean age of 784 days (December 2014). Therefore, the sex effect is confounded with age, but this age of slaughter difference reflects a target slaughter live weight of 500 kg for heifers and 600 kg for steers which is commercial practice in New Zealand. Cattle were slaughtered as described in Coleman et al. (2016) at a Ministry of Primary Industry New Zealand approved abattoir following the New Zealand Code of Animal Welfare for transport (2011) and the New Zealand Code of Animal Welfare for slaughter of commercial animals (2010).

2.2. Live weight

Unfasted live weight of the heifers and steers was measured at weaning and when the steers and heifers were split and managed separately (presented as 11-month weight). Heifers were weighed at 553-days of age and the steers at 785-days of age, which was used as the final live weight for this experiment. Average daily gain (ADG) was calculated for the period between weaning and 11-month weight (131-day period), and between weaning and final live weight (Heifers = 360 days, Steers = 590 days).

2.3. Carcass characteristics

Ultrasound assessment (Aquila Portable Ultrasound, Biosound Esoate, Esoate S.p.A, Genova, Italy using an 18 mm probe) of carcass traits was conducted at a mean age of 415, and 553 days for all cattle and additionally at 723 days of age for the steers. Measurements made were eye muscle area (EMA), being the transverse area of the *Longissimus thoracis*, intramuscular fat content (IMF) of the *Longissimus thoracis* and subcutaneous rib fat depth over the *Longissimus thoracis*, all measured between the 12th and 13th rib. Subcutaneous fat depth was also measured at the P8 site on the rump (P8 fat depth) (Hopkins, 1989).

Treatment of carcasses, and meat sampling was the same as previously described in Coleman et al. (2016). Briefly, carcasses underwent commercial dressing procedures at Land Meats Whanganui, New Zealand and carcasses were split down the midline. Carcass weight was obtained by summing the weight of the two halves obtained prior to their entry into the chiller. Carcass length was measured on each half of the carcass from the distal end of the tarsal bone to the mid-point of the cranial edge of the first rib (Purchas, Burnham, & Morris, 2002) and the mean of the length for the two halves used as the length of the carcass. The dressing-out percentage was calculated as the carcass weight divided by the final body weight recorded on-farm. As final live weight was recorded 3-weeks prior to slaughter for heifers, dressing out percentage was only calculated for the steers and only analysed to consider differences between the dam breeds.

The area of the *Longissimus thoracis* (eye muscle) was traced and the subcutaneous fat depth, at a point where the *Longissimus thoracis* was deepest (rib fat), was measured on the chilled, quartered carcass (cut between 12th and 13th rib) 24 h post-slaughter. The area of the tracing was measured using a planimeter (Placon KP 90 N, Tokyo, Japan) to provide a direct measure of eye muscle area (EMA). A sample of the *Longissimus lumborum* muscle (striploin) including the overlying subcutaneous fat was taken from between the first and third lumbar vertebrae on the right half of the carcass. Samples were vacuum packed (Ultrasource Ultravac UV800, Kansas City, MO, USA), aged for 7 days at 1 °C and then frozen at −20 °C for 27 weeks.

2.4. Meat quality

Meat quality testing methodology is the same as previously described in Coleman et al. (2016). Samples were randomly assigned to one of seven test days, ensuring each breed cross and sex was tested each day. Striploin samples were thawed for 24 h at 4 °C. To measure water loss from thawing, the thawed, vacuum-packed sample was weighed before opening, then the sample and packaging were blotted dry using tissue paper and weighed. Thaw loss was calculated as the unopened weight, less the sample and packaging weight, expressed as a percentage of unwrapped sample minus the packaging weight.

Ultimate pH was measured at three points on a transverse, internal cut with a pH spear (Eutech Instruments, Singapore), calibrated to pH 4.01, 7.00 and 10.01 buffers. A piece of the end portions of the sample was filtered through 231 μm mesh after a standard homogenization to measure myofibrillar fragmentation index (MFI) (Purchas, Hartley, Xun, & Grant, 1997). Muscle fiber samples were compressed between glass slides and a helium-neon gas laser (632.8 nm, Melles Griot, Carlsbad, CA, USA) was used to create a diffraction pattern and measure sarcomere length (Bouton, Fisher, Harris, & Baxter, 1973).

Thirty minutes after cutting, lean meat color (L^* (lightness), a^* (redness) and b^* (yellowness)) was measured using a Minolta Color Meter calibrated to a standard white tile (CR-200, Konica Minolta Photo Imaging Inc., Mahwah, NJ, USA) set to Illuminant D65, 8 mm aperture, 0° standard observer. Subcutaneous fat color (b^* only) was assessed using the same technique. A mean of three measurements from each sample was used for analysis.

Two steaks, 25 mm steak and 40 mm respectively were cut from the center of the striploin sample. The 25 mm steak was weighed, bagged, and cooked in a water bath at 70 °C for 90 min before being chilled at 1 °C for 24 h, when it was weighed again. All samples were cooked together in a single water bath. Cooking loss was calculated as pre-cooking weight less post-cooking weight, expressed as a percentage of the pre-cooking weight. Drip loss was assessed by suspending a weighed 40 mm cube cut from the 40 mm steak, in a bag from a metal hook at 1 °C. The cube was re-weighed after 24 and 48 h and drip loss expressed as a percentage of the original weight. Expressed juice was measured by pressing 0.5 g of the meat onto Whatman No. 1 filter paper between two Perspex plates for 2 min using a 10 kg weight. A planimeter (Placom KP-90 N, Tokyo, Japan) was used to measure the wetted area and the result expressed as wet area per g of steak (Purchas & Aungsupakorn, 1993).

Shear force (work done, initial yield and peak force, Purchas and Aungsupakorn (1993)) was measured on twelve 13 mm cores from the cooked 25 mm steak for each sample, using a square blade at right angles to the fiber axis (50 mm blade with a 25 mm horizontal cutting section and blade thickness of 1.016 mm, crosshead speed of 230 mm/min; G-R Electric Manufacturing, Manhattan, KS, USA).

An internal portion of the remaining sample was trimmed of subcutaneous fat, minced (Kenwood benchtop mincer, 3 mm hole plate) and analysed for intramuscular fat (IMF) content by SOXTEC ether extraction (AOAC, 1990; method 991.30).

2.5. Statistical analysis

The analysis of data used general linear and mixed models in SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

Steers and heifers and were considered separately for live weight, growth rate (as average daily gain) and ultrasound carcass traits. Live weight and growth rate were analysed using general linear models and ultrasound carcass traits were analysed using mixed models. All statistical models included breed-cross as a fixed effect. The ultrasound carcass trait models included day of measurement as a repeated measure and animal as a random effect. Deviation from mean date of birth was considered as a covariate for all live animal measurements but removed from the model if it was not significant. For growth and ultrasound traits, the experimental units were individual animals within breed-cross treatment managed together for each sex.

For the carcass characteristics measured on the carcass and meat quality measurements, data from heifers and steers were analysed together in general linear models. Breed-cross, sex and their interaction were included as fixed effects in all models. Additionally, birthdate deviation was included as a covariate in the model for carcass weight, and carcass weight was included as a covariate for the analysis of carcass length and eye muscle area. For all meat quality measurements, the statistical model included the day of measurement as a covariate effect, ultimate pH was also fitted as a covariate effect for all models aside from pH. For carcass and meat quality traits, the experimental units were individual animals within breed-cross and sex treatment.

3. Results

3.1. Live weight

The C-AA heifers were lightest at weaning, and C-AF heifers the heaviest (Table 1, $P < 0.05$). Weight of heifers at 11-months-of-age, when steers and heifers were separated, and the final live weight did not differ between breed-crosses (Table 1, $P > 0.05$). There were no differences in growth rate between weaning and 11-months among the breed-crosses (Table 1, $P > 0.05$). However, over the entire period from weaning until final weight was taken, the C-AA heifers had a faster growth rate from weaning to final live weight than the other breed crosses (Table 1, $P < 0.05$).

At weaning, C-AA steers were lighter than the other breed-crosses (Table 1, $P < 0.05$), but there were no significant differences among the breed-crosses in the 11-month or final live weight, nor in either measure of growth rate of the steers among breed-crosses during this experiment (Table 1, $P > 0.05$).

Table 1
Live weight and growth between weaning and slaughter of Charolais sired heifers and steers born to Angus-cross-dairy cows.

	Breed-cross[1]				*P*-value[2]
Growth characteristic[3]	C-AA	C-AF	C-AK	C-AJ	Age deviation
Heifers					
n	16	11	9	17	
Weaning weight (kg)	226.0 ± 4.8[a]	258.7 ± 5.7[c]	254.0 ± 6.4[bc]	241.1 ± 4.7[b]	<0.001
11-month weight (kg)[4]	301.0 ± 6.9	320.5 ± 8.2	315.7 ± 9.2	302.9 ± 6.8	<0.001
Weaning to 11-month average daily gain (g)[5]	565 ± 37	477 ± 44	461 ± 49	481 ± 35	
Final live weight (kg)[6]	493.0 ± 7.9	517.6 ± 9.5	491.0 ± 10.5	485.6 ± 7.6	
Weaning to slaughter average daily gain (g)[7]	757 ± 15[b]	709 ± 18[a]	678 ± 20[a]	662 ± 15[a]	
Steers					
n	17	11	7	15	
Weaning weight (kg)	238.6 ± 4.5[a]	268.0 ± 5.5[b]	256.4 ± 6.9[b]	256.3 ± 4.8[b]	<0.001
11-month weight (kg)[4]	319.0 ± 7.3	346.4 ± 9.0	335.7 ± 11.2	324.0 ± 7.8	<0.001
Weaning to 11-month average daily gain (g)[5]	617 ± 38	600 ± 47	607 ± 59	511 ± 41	
Final live weight (kg)	645.2 ± 10.4	662.0 ± 12.5	640.3 ± 17.0	640.5 ± 10.7	
Weaning to slaughter average daily gain (g)[7]	684 ± 14	665 ± 16	653 ± 22	660 ± 14	

[ab]Within a row, means with no superscripts or with a common superscript letter are not significantly different ($P < 0.05$).
[1] Charolais (C) sired heifers and steers born to Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows.
[2] *P*-values for deviation from mean date of birth (age deviation) fitted in analysis of weaning and 11-month weight.
[3] Values are least squares means ± standard error of the mean.
[4] Weight when steers and heifers separated and managed separately, mean age 324-days.
[5] Average daily gain calculated for the period from weaning until steers and heifers separated, 131-day period.
[6] Final live weight taken as weight at 553 (average) days of age, three weeks prior to slaughter.
[7] Average daily gain calculated for the period from weaning until final live weight, Heifers: 360-day period, Steers: 590-day period.

3.2. Carcass characteristics

Carcass characteristics measured by ultrasound were similar among the breed-crosses for heifers (Table 2, $P > 0.05$). Eye muscle area, rib fat depth and P8 fat depth were greater in heifers at 553 days than 415 days of age (Table 2, $P < 0.001$).

The C-AA steers had a greater fat depth (rib and rump) than other breed-crosses (Table 2, $P < 0.05$). All steer breed-crosses had a similar proportion of intramuscular fat in the eye muscle (Table 2). Steers had a greater eye-muscle area, fat depth over the rib and rump sites and intramuscular fat percentage at 553 days of age than at 415 and 723 days (Table 2, $P < 0.01$).

The dressing-out percentage for C-AA steers of 53.1 ± 0.3% was greater ($P < 0.01$) than C-AF (51.9 ± 0.4%) and C-AJ steers (51.5 ± 0.3%); the C-AK steers (52.0 ± 0.5) were not different to other breed-crosses. Dressing out percentage was not calculated for the heifers.

Table 2
Carcass characteristics measured by ultrasound at 415, 553 and 723 days-of-age, on Charolais sired heifers and steers born to Angus-cross-dairy cows.

	Breed-cross[1]				Age (days)		
Carcass characteristic[2]	C-AA	C-AF	C-AK	C-AJ	415	553	723 [3]
Heifers							
EMA (cm^2)	70.0 ± 1.6	73.3 ± 1.9	75.0 ± 2.1	68.7 ± 1.5	68.5 ± 0.7^{a}	75.0 ± 1.6^{b}	
Rib fat depth (mm)	2.9 ± 0.2	2.5 ± 0.2	2.8 ± 0.2	2.6 ± 0.2	2.3 ± 0.1^{a}	3.1 ± 0.2^{b}	
IMF (%)	2.9 ± 0.7	3.6 ± 1.0	3.1 ± 1.1	4.9 ± 0.8	3.2 ± 0.2	4.0 ± 0.9	
P8 fat depth (mm)	4.5 ± 0.2	4.4 ± 0.3	4.3 ± 0.3	4.6 ± 0.2	3.6 ± 0.1^{a}	5.3 ± 0.2^{b}	
Steers							
EMA (cm^2)	71.0 ± 0.8	72.0 ± 1.0	72.3 ± 1.2	69.9 ± 0.9	69.8 ± 0.8^{a}	75.7 ± 0.8^{b}	68.6 ± 0.9^{a}
Rib fat depth (mm)	2.8 ± 0.1^{b}	2.2 ± 0.1^{a}	1.9 ± 0.2^{a}	2.0 ± 0.1^{a}	2.0 ± 0.1^{a}	2.7 ± 0.1^{b}	1.9 ± 0.1^{a}
IMF (%)	3.3 ± 0.2	3.0 ± 0.2	2.9 ± 0.3	3.0 ± 0.2	2.9 ± 0.2^{a}	3.6 ± 0.2^{b}	2.6 ± 0.2^{a}
P8 fat depth (mm)	4.2 ± 0.1^{b}	3.8 ± 0.2^{ab}	3.4 ± 0.2^{a}	3.5 ± 0.2^{a}	3.5 ± 0.1^{b}	5.1 ± 0.2^{c}	2.6 ± 0.1^{a}

[ab]Within a row and either within breed-cross or sex groups, means with no superscripts or with a common superscript letter are not significantly different ($P < 0.05$).
[1] Charolais (C) sired heifers and steers born to Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows.
[2] EMA: eye-muscle (*Longissimus thoracis*) area, rib fat depth: subcutaneous fat depth over eye-muscle, IMF intramuscular fat in eye-muscle, P8 fat depth: subcutaneous fat depth over rump. Values are least squares means ± standard error of the mean.
[3] No 723-day measurement taken on the heifers.

For carcass characteristics measured directly on the carcass there were no difference among breed-crosses for carcass weight (adjusted for age), length (adjusted for carcass weight), eye muscle area (adjusted for carcass weight), rib fat depth, or intramuscular fat percentage (Table 3, $P > 0.05$). There was an interaction between breed and sex for rib fat depth as C-AA steers had a greater rib fat depth than C-AK steers, but this was not evident for the heifers (Table 3, $P = 0.027$). Steers had longer (adjusted for carcass weight), heavier carcasses with a greater rib fat depth and intramuscular fat in the *Longissimus lumborum* muscle than heifers (Table 3, $P < 0.01$).

3.3. Meat quality

There were no interactions between sex and breed-cross for any meat quality trait (except for ultimate pH, all traits were adjusted for pH). Other than fat color, there were no differences among breed-crosses for meat quality characteristics (Table 4, $P > 0.05$). Fat from C-AJ cattle was yellower than fat from C-AA cattle, while C-AF and C-AK cattle were not different to all breed crosses (Table 4, $P < 0.05$).

There were no differences between the meat from heifers and steers for MFI, sarcomere length, meat lightness, yellowness, expressed juice, cooking loss and drip loss (Table 4). Steers had a higher ultimate pH, and greater peak shear force and thaw loss than heifers (Table 4, $P < 0.01$). Steers also had redder meat and, yellower fat than heifers (Table 4, $P < 0.001$).

4. Discussion

Beef cattle are selected for their ability to gain live weight, have high meat yields and to produce desirable meat quality attributes. Steers are known to achieve greater growth rates than heifers, and at similar carcass weight, carcasses from heifers have greater fat content than steers (Bures & Barton, 2012; Irshad et al., 2013; Lage et al., 2012; Wilson et al., 1969). Producers respond to these differences by processing the cattle at different live weight, to produce smaller carcasses from heifers than steers but with a similar carcass fat. The objective of this experiment was to compare the carcass characteristics and meat quality of heifers and steers from breeds with different growth potential when they were processed at commercially relevant weights for New Zealand production.

4.1. Growth characteristics

Milk production of the beef cow is a strong driver of the weaning weight achieved by her progeny (Hickson et al., 2014; Meyer, Carrick, & Donnelly, 1994). The higher weaning weight for the steers born to the Angus-cross-dairy cows is likely to reflect a higher milk intake due to the dairy breed influence on milk production (Hickson et al., 2015; Roca Fraga et al., 2013). The year prior to this experiment, milk yeild and lactation curves of the same cows used in this experiment were estimated using weigh-suckle-weigh techniques, finding that the AF, AJ and AK cows produced 240–235 kg more milk throughout lactation, including reaching a greater and later lactation peak yield, compared to the AA cows (Roca Fraga et al., 2013). The differences among breed-crosses are consistent with weaning weights from previous calves born to the same dams as used in the present experiment (Coleman et al., 2016;Law et al., 2013; Vazquez et al., 2013).

Despite the lighter weaning weight and indicated lesser milk production of the dams (Roca Fraga et al., 2013) of the C-AA cattle, and a similar live weight at 11-months-of-age, there was no significant

Table 3
Carcass characteristics measured directly on the carcass or eye-muscle (*Longissimus thoracis)* of Charolais sired heifers and steers born to Angus-cross-dairy cows.

	Breed-cross[1]				Sex		*P*-value[2]	
Carcass characteristic[3]	C-AA[4]	C-AF	C-AK	C-AJ	Heifers	Steers[3]	Age deviation	Carcass weight
n	33	22	16	32	53	50		
Hot carcass weight (kg)	291.6 ± 3.6	296.3 ± 4.4	288.7 ± 5.2	282.1 ± 3.6	238.8 ± 2.9^{a}	340.4 ± 3.1^{b}	<0.001	
Carcass length (mm)	2239 ± 8	2262 ± 10	2251 ± 12	2258 ± 9	2218 ± 13^{a}	2287 ± 14^{b}		<0.001
Eye muscle area (cm^2)	80.9 ± 2.0	84.0 ± 2.5	84.4 ± 2.8	83.2 ± 2.0	84.4 ± 3.0	81.9 ± 3.3		<0.001
Fat depth (mm)	4.8 ± 0.3	4.1 ± 0.3	3.8 ± 0.4	4.1 ± 0.3	3.3 ± 0.2^{a}	5.1 ± 0.2^{b}		
Intramuscular fat (%)	1.88 ± 0.10	1.92 ± 0.13	2.14 ± 0.15	2.21 ± 0.10	1.71 ± 0.08^{a}	2.36 ± 0.09^{b}		

[ab]Within a row and either breed-cross or sex groups, means with no superscripts or with a common superscript letter are not significantly different ($P<0.05$).
[1] Charolais (C) sired heifers and steers born to Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows.
[2] *P*-values for deviation from mean date of birth (age deviation) fitted in analysis of carcass weight, and carcass weight fitted in analysis of carcass length and eye muscle area.
[3] Values are least squares means ± standard error of the mean.
[4] One C-AA steer did not have a meat sample taken and was not analysed for intramuscular fat.

Table 4
Meat quality characteristics of striploin (*Longissimus lumborum*) from Charolais sired heifers and steers born to Angus-cross-dairy cows.

	Breed-cross[1]				Sex		*P*-value [2]	
Meat quality characteristic[3]	C-AA	C-AF	C-AK	C-AJ	Heifers	Steers	pH	Day
n	32	22	16	32	53	49		
Ultimate pH	5.64 ± 0.02	5.62 ± 0.02	5.59 ± 0.03	5.61 ± 0.02	5.56 ± 0.01[a]	5.67 ± 0.02[b]		0.027
MFI (%)	96.5 ± 0.7	98.3 ± 0.8	97.8 ± 0.9	97.4 ± 0.7	98.1 ± 0.6	97.0 ± 0.6	0.855	0.314
Sarcomere length (μm)	1.86 ± 0.02	1.87 ± 0.03	1.82 ± 0.03	1.86 ± 0.02	1.86 ± 0.02	1.85 ± 0.02	0.742	0.586
Shear force (N)								
Peak force	88.8 ± 3.1	90.9 ± 3.7	81.9 ± 4.4	86.6 ± 3.0	81.6 ± 2.6[a]	92.5 ± 2.7[b]	0.103	0.205
Initial yield	27.8 ± 0.7	26.6 ± 0.8	26.1 ± 1.0	25.8 ± 0.7	24.6 ± 0.6[a]	28.5 ± 0.6[b]	0.330	0.630
Work done	26.5 ± 0.8	26.7 ± 1.0	24.6 ± 1.2	25.6 ± 0.8	25.9 ± 0.7	25.8 ± 0.7	0.015	0.085
Lean color								
Meat L^* (lightness)	37.7 ± 0.4	37.4 ± 0.5	39.1 ± 0.6	37.9 ± 0.4	37.8 ± 0.4	38.2 ± 0.4	0.821	0.092
Meat a^* (redness)	14.3 ± 0.2	14.5 ± 0.3	14.7 ± 0.3	14.9 ± 0.2	13.7 ± 0.2[a]	15.5 ± 0.2[b]	<0.001	0.312
Meat b^* (yellowness)	4.0 ± 0.2	4.2 ± 0.2	4.3 ± 0.2	4.3 ± 0.1	4.0 ± 0.1	4.4 ± 0.1	0.041	0.220
Subcutaneous fat color								
Fat b^* (yellowness)	11.7 ± 0.3[a]	12.0 ± 0.4[ab]	12.6 ± 0.5[ab]	13.0 ± 0.3[b]	11.4 ± 0.3[a]	13.3 ± 0.3[b]	0.239	0.039
Water-holding measures								
Expressed juice (cm^2/g)	31.2 ± 0.5	30.1 ± 0.6	30.7 ± 0.7	30.8 ± 0.5	30.6 ± 0.4	31.2 ± 0.4	0.607	0.343
Drip loss after 24 h (%)	7.1 ± 0.5	6.4 ± 0.5	6.0 ± 0.7	6.2 ± 0.5	6.6 ± 0.4	6.2 ± 0.4	0.032	0.021
Drip loss after 48 h (%)	8.7 ± 0.5	8.0 ± 0.6	8.2 ± 0.8	8.2 ± 0.5	8.5 ± 0.5	8.0 ± 0.5	0.019	0.009
Thaw loss (%)	2.5 ± 0.3	2.5 ± 0.3	3.2 ± 0.4	2.4 ± 0.3	1.8 ± 0.2[a]	3.5 ± 0.2[b]	<0.001	0.019
Cooking loss (%)	26.4 ± 0.3	26.4 ± 0.4	27.0 ± 0.4	26.3 ± 0.3	26.3 ± 0.3	26.8 ± 0.3	0.302	0.839

[ab]Within a row and either breed-cross or sex groups, means with no superscripts or with a common superscript letter are not significantly different (P < 0.05).
[1] Charolais (C) sired heifers and steers born to Angus (AA), Angus-Friesian (AF), Angus-Kiwi (AK) and Angus-Jersey (AJ) cows.
[2] *P*-values for ultimate pH and measurement day fitted in analysis of each characteristic.
[3] Values are least squares means ± standard error of the mean.

difference in the growth rate over the ~4 months following weaning between heifer and steer breed-crosses. Small numerical differences in the growth rate of heifers between weaning and 11-months-of-age (84–104 g/day) could indicate some compensatory growth of the C-AA heifers, however, the same numerical difference was not seen in the steers. Compensatory growth indicates there was a period of nutritional restriction (Sainz, De la Torre, & Oltjen, 1995), which has not been indicated in progeny from straightbred Angus cows relative to Angus-cross-dairy cows in previous experiments, rather that the differences in weaning weights are due to increased milk production, and therefore increased weaning efficiency of the Angus-cross-dairy cows relative to the straightbred Angus cows (Law et al., 2013; Vazquez et al., 2013).

There was no difference in the final weight among breed-crosses of either sex despite differences in weaning weight and the overall growth rate in the heifers. This is consistent with steer progeny from a previous cohort of steers from these mixed-aged cows (Collier et al., 2015), but differs from the first cohort of steers from these (primiparous) cows, for which steers born to AF cows were heavier from weaning to finishing (Coleman et al., 2016). Twomey, Ring, McHugh, and Berry (2020) suggested that in addition to genotype effects on growth, early life feeding will influence final liveweight and carcass weights obtained when comparing beef-cross-beef and beef-cross-dairy cattle so, the lack of difference in final weight observed maybe partly due to all offspring being raised with their dam. Also, of consideration for growth performance between studies is the effect of the beef-sire breed as it has been noted in studies comparing beef-cross-dairy cattle that large differences in performance characteristics exist between sire breeds (Berry, 2021).

The growth rates and age at slaughter for both heifers and steers were consistent with industry norms for cattle finished in pastoral grazing systems in NZ (Geenty & Morris, 2017).

4.2. Carcass characteristics

As expected, given the differences in live weight and age at slaughter (on average, 153 kg heavier and 204-day older), carcasses from steers were heavier and longer than carcasses from heifers. The greater intramuscular fat of the steers is consistent with previous work which shows intramuscular fat percentage increases with age and carcass weight (Arthaud, Mandigo, Koch, & Kotula, 1977; Irshad et al., 2013).

Dressing out percentage in the present experiment was the only trait which differed among breed-crosses. The greater dressing-out percentage for the C-AA beef breed cattle compared to C-AF and C-AJ cattle, corroborates previous research where dressing out percentages for beef-breeds were greater compared to those of dairy-breeds (Alberti et al., 2008; Barton & Pleasants, 1997; Coleman et al., 2016; Collier et al., 2015; Morris, Baker, Carter, & Hickey, 1990; Purchas & Morris, 2007). These breed effects are from dairy breeds having a greater weight of non-carcass tissues, in particular the gastrointestinal tract, and the partitioning of fat into non-carcass tissues while beef breeds will have a higher muscle to bone ratio (Barton & Pleasants, 1997; Keane, 2010; Muir et al., 2000).

4.3. Meat quality

The yellower fat from C-AJ cattle than C-AA cattle is consistent with previous reports that dairy breeds have a tendency for yellower fat, especially Jersey (Burke et al., 1998; Morgan & Everitt, 1969; Purchas, 2003; Purchas & Morris, 2007; Walker, Warner, & Winfield, 1990). Although there was an instrumentally measured difference in the fat color, when carcasses were graded at slaughter, none were penalized for yellow fat. The sensitivity of the chromameter for detecting differences in color, are unlikely to reflect the difference requires to meet the threshold for detection by the human eye and so visual scoring at the time of grading is likely the best mechanism to detect yellowness faults of the fat.

The yellower fat of steers than heifers could be a consequence of seasonal (pre-winter heifer slaughter vs late spring steer slaughter) as well as age differences allowing for time for the deposition of yellow pigments in the fat (Kirton & Morris, 1989; Morgan & Everitt, 1969; Muir et al., 2000; Seideman et al., 1984). The absence of an interaction between sex and breed-cross indicates that there may be an advantage for heifers in that they are processed younger and earlier in the season, so they are less likely to have yellow fat than steers, and so Jersey-component heifers may be less likely to trigger downgrading for reaching the yellowness threshold during carcass grading. Steers also had redder meat than the heifers, which is likely an effect increasing concentration of myoglobin in the older cattle (Priolo, Micol, & Agabriel, 2001; Seideman et al., 1984).

The comparable ultimate pH for the breed-crosses reflects the cattle being managed and handled in the same manner prior to slaughter and no incidence of dark-cutting. The similar myofibrillar fragmentation index indicates that the breed treatments did not have differences in their muscle proteolytic activity over the 7-day aging period. The sarcomere length values are within the range expected for cattle and were similar between the breed-crosses reflecting that no cold-shortening had occurred in the absence of electrical stimulation and that there were no differences in chilling rate due to similar fat depths and post-mortem chilling treatment for all carcasses (Purchas & Zou, 2008).

The ultimate pH for the meat samples from steers was higher than that of heifers, however, at a difference of only 0.11 pH units, although statistically different, because the pH values fall in the range for desirable meat quality attributes the differences between heifers and steers is unlikely to be significant for meat quality. Martín et al. (2018) demonstrated pH varies considerably among similar cattle processed on different days, so there may be many confounding factors, unrelated to sex or breed-cross impacting this difference.

Generally, the steers produced meat that had higher shear force values than the heifers. Tenderness differences seen in the present experiment are likely linked to the older age of the steers. Slaughter age effects on tenderness are mediated through intramuscular fat content and collagen solubility (Muir et al., 2000; Purchas, 2003) while a comparison of heifers and steers suggests there is no direct sex effect on tenderness of beef (Lucero-Borja et al., 2014).

Values obtained from the meat quality tests indicated that the beef from both steers and heifers was of acceptable eating quality. Ultimate pH was generally with the desired range (5.5–5.8) for beef produced under New Zealand grazing conditions (Coleman et al., 2016; Martín et al., 2022; Purchas et al., 2002; Purchas & Morris, 2007). Water holding capacity measures, lean and fat color and intramuscular fat percentages were within previously reported ranges from New Zealand cattle finished on pasture (Coleman et al., 2016; Martín et al., 2022; Purchas et al., 2002). Although 48% of samples had a^*-values below the 14.5 threshold for acceptable red color (Holman, van de Ven, Mao, Coombs, & Hopkins, 2017), it is unlikely that differences (range 10.7–17.8) would be detectable by customers especially since there is a low correlation between chromameter values and acceptability scores for color of beef (Shorthose, Harris, Hopkins, & Kingston, 1988) Peak shear force values were largely above international thresholds for acceptable meat tenderness (<55.9 N) (Holman, Collins, Kilgannon, & Hopkins, 2020; Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Platter et al., 2003). However, peak force values were similar to New Zealand pasture-fed cattle (Coleman et al., 2016; Purchas et al., 2002) and are likely to reflect an older age of slaughter for cattle finished in grazing systems and that the beef would benefit from an extended aging period.

5. Conclusion

Angus-cross-dairy breed heifers and steers produced meat with equal meat quality characteristics when heifers were processed at 500 kg live weight and steers at 600 kg target live weight, 210 days later. Carcasses from steers were heavier, longer and had greater intramuscular fat, and so would have generated greater income for the farmer based on carcass classification criteria used in New Zealand. Despite slower growth and a lower dressing out percentage from the Jersey-cross cattle, the carcass and meat quality measurements were consistent across the beef breed and beef-cross-dairy breeds used in this study and so, farmers do not need to be concerned about a dairy component within the breeding of cattle being used for beef production.

Using Angus-cross-dairy cows to produce progeny for beef production can be a useful strategy to utilize surplus animals from the dairy industry. The Angus-cross-dairy breeding cow when crossed with a beef breed sire such as the Charolais will provide progeny which are competitive to the progeny of the Angus beef cow, for beef finishing and meat production.

Funding

The funding sources of this research have been noted in the manuscript. The funding bodies had no involvement in the study design, data collection, analysis, or interpretation, writing of the manuscript or decision to submit the results for publication.

Ethical statement

The study was conducted according to the guidelines of the Massey University Code of Ethical Conduct for the Use of Animals for Research, Testing and Teaching, and approved by the Animal Ethics Committee of Massey University, New Zealand (protocol codes 09/21 and 12/27).

CRediT authorship contribution statement

Lucy W. Coleman: Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Nicola M. Schreurs:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing, Supervision. **Paul R. Kenyon:** Conceptualization, Writing – review & editing, Funding acquisition. **Stephen T. Morris:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Rebecca E. Hickson:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

Acknowledgements

This research was funded by Massey University, Beef + Lamb NZ and the C. Alma Baker Trust. Authors are grateful to Massey University technical and farm staff for their assistance with the implementation of the experiment. Authors would like to thank staff at Land Meat in Whanganui for allowing the authors to come on site to collect samples and measurements.

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