

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

Jerad R. Jaborek,* Henry N. Zerby,* Steven J. Moeller,* Francis L. Fluharty,[†] and Alejandro E. Relling^{‡,1,◉}

*Department of Animal Sciences, The Ohio State University, Columbus, OH 43210; [†]Department of Animal and Dairy Sciences, University of Georgia, Athens, GA 30602; and [‡]Department of Animal Sciences, The Ohio State University, Wooster, OH 44691

ABSTRACT: Feedlot performance, carcass yield, fatty acid composition, and tenderness of crossbred Jersey steers compared with purebred Jersey steers was investigated. Purebred Jersey ($n = 21$) and crossbred Jersey steers sired by Angus ($n = 9$), SimAngus ($n = 10$), and Red Wagyu ($n = 15$) bulls were assessed. Adjusted to a common initial body weight (BW), crossbred Jersey steers had a greater rate of BW gain ($P \leq 0.01$) compared with purebred Jersey steers. Angus sired steers had a greater daily dry matter intake ($P \leq 0.01$) compared with Wagyu and Jersey sired steers, whereas SimAngus sired steers had a greater daily dry matter intake compared with Jersey sired steers. Wagyu sired steers were more feed efficient ($P \leq 0.03$) compared with Jersey sired steers. Even with a greater ($P \leq 0.01$) number of days on feed, off-test BW of purebred Jersey steers was less ($P \leq 0.01$) compared with crossbred Jersey steers. Adjusted to a common hot carcass weight, Angus sired steers had a greater backfat thickness ($P \leq 0.01$) compared with steers from the other sire breeds. Kidney fat percentage ($P \leq 0.01$) was greatest for Jersey sired steers, with SimAngus and Wagyu sired steers being intermediate, and the lowest for Angus sired steers. Carcasses from Angus and Wagyu

sired steers had a greater marbling score ($P \leq 0.03$) compared with carcasses from Jersey sired steers. Carcasses from Wagyu sired steers had a greater ($P \leq 0.01$) total red meat yield compared with Angus and Jersey sired steers, whereas SimAngus sired steers had a greater total red meat yield compared with Jersey sired steers. Carcasses from Angus sired steers tended ($P = 0.07$) to have a greater percentage of fat trim compared with Wagyu sired steer carcasses. There were no sire breed differences ($P = 0.38$) for the percentage of total bone from the carcasses. Tenderness, measured by Warner-Bratzler shear force (WBSF), was improved ($P \leq 0.01$) with 14 d of postmortem aging compared with 7 d. Wagyu and SimAngus sired steers produced steaks with a lesser ($P \leq 0.01$) WBSF compared with steaks from Angus and Jersey sired steers. Steaks from Angus sired steers tended ($P = 0.10$) to have a greater percentage of total lipid and had a greater ($P \leq 0.05$) percentage of 16:0 compared with steaks from Jersey sired steers. Overall, crossbred Jersey steers improved economically relevant production parameters of feedlot performance, carcass quality, carcass yield, and instrumental predictors of eating quality compared with purebred Jersey steers.

Key words: breed, crossbreeding, feedlot, Jersey, yield

© The Author(s) 2019. Published by Oxford University Press on behalf of the American Society of Animal Science. This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com

Transl. Anim. Sci. 2019.3:1475–1491
doi: 10.1093/tas/txz110

¹Corresponding author: relling.1@osu.edu

Received April 10, 2019.

Accepted July 2, 2019.

INTRODUCTION

Jersey cattle are a dairy breed and are not typically thought of contributing to the fed beef supply. However, Jersey bull calves are a byproduct of the dairy industry and contribute to the fed beef supply. The incorporation of Jersey genetics continues to increase in the United States dairy industry as shown by a 10.85% increase in domestic semen sales from 2012 to 2013 and a 7.75% increase from 2013 to 2014 (NAAB, 2015). According to the 2016 National Beef Quality Audit, dairy type cattle accounted for 16.3% of the fed cattle harvested (Boykin et al., 2017). Therefore, as the influence of Jersey genetics increases, there are likely to be more Jersey influenced steer calves available to be raised for beef production in the future.

Jersey cattle are smaller framed, slower growing, and finely muscled compared with other breeds of cattle, especially beef cattle breeds (Cole et al., 1964; Koch et al., 1976). As a result, the sale of purebred Jersey male calves provides very little economic return to Jersey dairy producers due to the anticipated poor growth and projected light finishing weights of purebred Jersey steers in the feedlot. In addition, fattened purebred Jersey steers also receive dairy-type discounts for light muscling when sold to the packing plant. These negative economic factors have resulted in little to no demand for purebred Jersey steers in the U.S. commercial beef industry. However, Jersey cattle can produce high quality beef with a superior eating satisfaction. Purebred Jersey cattle can deposit sufficient amounts of marbling to receive Low to Average Choice USDA Quality grades (Lehmkuhler and Ramos, 2008; Arnett et al., 2012). Cole et al. (1964) reported similar marbling scores between Jersey steers and British (Angus and Hereford) steers. Subsequently, Jersey steers were reported to have the greatest tenderness, flavor, and juiciness scores for loin and round steaks compared with other breeds of cattle (Hereford, Angus, Brahman, Brahman cross, Santa Gertrudis, Holstein, and Charolais cross) when assessed by both a laboratory and family panel (Ramsey et al., 1963; Cole et al., 1964). A trained sensory panel described by Arnett et al. (2012) reported greater tenderness, juiciness, beef flavor intensity, and overall acceptability scores for strip steaks from Jersey steers offered a high concentrate diet compared with commodity derived strip steaks that represented commodity boxed beef sold in the United States. Therefore, Jersey beef may be more suitable for niche markets or value-added markets, such as white tablecloth restaurants and certain

export markets that demand high quality beef products with superior eating satisfaction. Niche markets commonly establish well defined labeling criteria that have a real or perceived positive effect on characteristics related to eating quality, sustainability, management or raising practices, human health benefits, and other attributes desired by the consumer.

This present study was designed to investigate the implementation of a crossbreeding program between Jersey cows and a terminal beef sire for the production of a high quality beef product to be sold into value added markets targeting the use of no exogenous growth promoting technologies (e.g., hormone implants and β -agonists), and to improve the value of male calves from Jersey herds through improved feedlot performance, carcass yield, and beef quality. We hypothesized the production of terminally sired crossbred Jersey calves, when compared with purebred Jersey calves, would result in improvements for economically relevant measures related to feedlot performance, carcass yield, and beef eating quality. The objectives of this study were to evaluate economically relevant measures related to the feedlot (average daily gain [ADG] and feed efficiency), carcass composition (muscle, fat, and bone yields), carcass quality (marbling and fatty acid composition), and beef tenderness (Warner-Bratzler shear force [WBSF]), with the overarching goal to assess their potential use in labeling claims to add value to products from Jersey influenced cattle.

MATERIALS AND METHODS

Animal procedures and husbandry practices were approved by the Institutional Animal Care and Use Committee (IACUC; protocol number 2015A00000093) of The Ohio State University and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Animals and Treatments

Purebred Jersey and crossbred Jersey steer calves were used in the present study. Purebred Jersey steers were sired by 11+ sires, while crossbred Jersey steer calves were produced by terminal sires from three breeds, Angus ($n = 1$ sire), SimAngus ($n = 2$ sires), and Red Wagyu ($n = 3$ sires); bulls within a terminal sire breed were selected for calving ease and marbling ability. The study was conducted as a randomized complete block design over the course

of 2 years (2015 and 2016), with year used as the block. Steer calves arrived at the Ohio Agricultural Research and Development Center (OARDC) feedlot with an average initial body weight (BW) of 210 ± 31 kg and an age of 237 ± 31 d with a sire breed occurrence of: Jersey ($n = 21$), Angus ($n = 9$), SimAngus ($n = 10$), and Red Wagyu ($n = 15$). The day after arrival, steer calves were weighed, ear-tagged, and vaccinated before being separated into individual pens. Each pen (2.6 m \times 1.5 m) consisted of concrete slatted floors, with a 1.5 m long concrete feed bunk, and supplied ad libitum access to clean fresh water.

Feeding and Management

Diets were formulated to meet the nutrient requirements of growing and finishing calves (NRC, 2000). Calves were offered a receiving diet

for approximately 30 d, a growing diet for 70 d, and two finishing diets for the remainder of the study (Table 1). Calves were transitioned over a 3-week period from the growing diet to the first finishing diet by substituting 10% of the corn silage for whole shelled corn. The first finishing diet containing corn silage was offered for approximately 100 d. The switch to the second finishing diet, which replaced corn silage with soy hulls, occurred over 1 d and was offered for the remainder of the feeding period. Feed allocation and feed refusals were weighed daily before feeding at 0930 to record individual feed intake. Feed samples were collected and saved every week to determine dry matter (DM) percentage (AOAC, 1984) and a composite sample of each dietary ingredient was analyzed for nutrient composition (Rock River Laboratory, Inc., Wooster, OH).

Table 1. Composition of diets offered during the experiment

Item	Receiving	Growing	Finishing corn silage	Finishing soy hulls
Ingredient	DM basis			
Whole shelled corn	15.00	20.00	50.00	55.00
DDGS	15.00	20.00	20.00	15.00
Soy hulls	0.00	0.00	0.00	20.00
Corn silage	60.00	50.00	20.00	0.00
Supplement	10.00	10.00	10.00	10.00
Ground corn	2.26	4.07	5.77	5.77
Urea	0.50	0.50	0.50	0.50
Soybean meal	5.45	2.00	1.00	1.00
Limestone	0.72	1.80	1.10	1.10
Dicalcium phosphate	0.11	0.00	0.00	0.00
White salt	0.16	0.50	0.50	0.50
Vitamin A, 30,000 IU/g	0.01	0.01	0.01	0.01
Vitamin D, 3,000 IU/g	0.01	0.01	0.01	0.01
Vitamin E, 44 IU/g	0.02	0.02	0.02	0.02
Calcium sulfate	0.40	0.70	0.70	0.70
Selenium, 201 ppm	0.02	0.04	0.04	0.04
Rumensin 90*	0.01	0.02	0.02	0.02
Potassium chloride	0.30	0.30	0.30	0.30
Cobalt carbonate	0.00	0.01	0.01	0.01
Copper sulfate	0.01	0.02	0.02	0.02
Zinc sulfate	0.02	0.01	0.01	0.01
Magnesium sulfate	0.01	0.00	0.00	0.00
Analyzed composition				
Crude protein, %	12.80	12.95	13.75	13.40
NDF, %	26.47	24.71	16.78	21.75
Fat, %	2.63	2.79	3.50	2.96
Ca, %	0.55	0.80	0.65	0.72
P, %	0.37	0.38	0.37	0.33
NEm, Mcal/kg	1.95	2.05	2.15	2.08
NEg, Mcal/kg	1.30	1.39	1.47	1.49

*Elanco Animal Health (Greenfield, IN).

Initial BW was measured the day after arrival to the OARDC feedlot, but before feeding for the day. Interim BW measurements were taken prior to feeding every 28 d to monitor BW gain and calf health. The targeted endpoint for steers was a live BW of 523 kg. Steers were removed in groups of 6 to 8 for harvest at 14 d intervals as target endpoints were reached. Due to the duration of time on feed needed for cattle to reach the predetermined harvest endpoint, some cattle (primarily purebred Jersey and Wagyu crossbreeds) had to be removed and harvested prior to reaching the target BW to provide feedlot pens for cattle the subsequent year. Off-test BW was recorded just before removal of the cattle from the feedlot.

Carcass Fabrication

Cattle were transported 160 km for harvest at The Ohio State University abattoir in Columbus, Ohio. The following day cattle were harvested and final BW and hot carcass weight (HCW) were recorded. After carcasses chilled for 7 d at 4 °C, chilled carcass weight was recorded and carcasses were split between the 12th and 13th ribs to determine backfat thickness (BFT), longissimus muscle area (LMA), carcass maturity, marbling score, USDA quality grade (QG), USDA yield grade (YG), and percent boneless closely trimmed retail cuts (BCTRC). CIELAB color (L*, a*, and b*) was measured with a Konica Minolta colorimeter CR-410 (Minolta Company, Ramsey, NJ), with a 50 mm diameter aperture and D65 illuminant calibrated against a white tile, on the longissimus muscle at the 12th rib and subcutaneous fat over the 11th and 12th ribs. Carcass kidney fat (KF) percentage was determined by the removal and weighing of the kidney fat during the fabrication process, divided by the chilled carcass weight.

The right side of each carcass was fabricated into primal and subprimal beef cuts according to USDA Agricultural Marketing Service's (AMS) Institutional Meat Purchase Specifications (IMPS) to determine carcass cutout yield and distribution (USDA, 2014). The following primal and subprimal weights were recorded: 112A ribeye roll, 124 back ribs, 114 shoulder clod, 114D top blade, clod teres major, 116A chuck roll, 116B chuck tender, 120 brisket, inside and outside skirt steak, 167A knuckle, 168 top/inside round, 171B bottom round, 171C eye of round, 174 short loin, 180 strip loin, 184 top sirloin butt, 184D top sirloin butt cap, 185B ball tip, 185D tri-tip, 191A butt tender, 192A tenderloin tail, 193 flank steak, 80:20 lean trim, fat trim, and bone weight.

Warner-Bratzler Shear Force

Four 2.54 cm thick steaks were cut from the posterior end of the ribeye roll and randomized to a postmortem aging period of either 7, 14, 21, or 28 d at 4 °C, and subsequently frozen at -20 °C. Before cooking, steaks were thawed over night at 4 °C. Cooking and WBSF were conducted according to guidelines set by the American Meat Science Association (AMSA, 2015). Cooking temperature was monitored using a thermocouple probe (5.08 cm Mini Needle Probe) and a thermocouple reader (ThermaData Thermocouple Logger KTC). Steaks were cooked on a flat top grill set at 190 °C, flipped at an internal temperature of 40 °C, and removed at an internal temperature of 71 °C. Steaks were allowed to cool over night at 4 °C. The next day, six round cores (1.27 cm diameter) were collected parallel to the muscle fibers from each steak. Cores were sheared perpendicular to the muscle fibers with a WBS v-notch blade using a TA.XT2 plus texture analyzer (Texture Technologies Corp., Scarsdale, NY). The crosshead speed was set at 200 mm/min and the peak force required to shear the sample was recorded.

Longissimus Fatty Acid Composition

Fatty acid extraction and methylation procedures used were from Folch et al. (1957) and Doreau et al. (2007), respectively. A thin slice of the longissimus muscle (~20 g), free of subcutaneous fat and connective tissue, was collected and frozen on day 7 from the ribeye roll for fatty acid composition analysis. Longissimus muscle samples were each ground in a blender to create a homogenous sample, from which 1 g of ground tissue was added to a pyrex tube containing a screw cap. In addition to the ground tissue, 2 ml of an internal standard (0.5 mg 19:0/ml; Nu-Chek Prep, Inc. Elysian, MN), 0.7 ml of 10N KOH in water, and 4.3 ml of methanol were added and vortexed for 120 s. Next, sample tubes were placed in a 55 °C hot water bath for 90 min, with 5 s of rigorous shaking taking place every 20 min for each sample. Samples tubes were placed in an ice water bath to cool samples to room temperature before adding 0.58 ml of 24N H₂SO₄ to each sample tube. Sample tubes were mixed by inversion and placed back in the 55 °C hot water bath for 90 min, with 5 s of rigorous shaking taking place every 20 min for each sample once again. Afterwards, sample tubes were cooled again in an ice water bath before the addition of 3 ml of hexane. Sample tubes were vortexed and centrifuged for

5 min each and then the hexane layer was extracted and placed in a gas chromatography vial to be analyzed. All fatty acid methyl esters were separated by gas-liquid chromatography using a CP-SIL88 capillary column (100 m × 0.25 mm × 0.2 µm film thickness). The indices of delta desaturation enzyme activity on the conversion of 14:0 to 14:1, 16:0 to 16:1, and 18:0 to 18:1 cis 9 were calculated as follows: [e.g., = 100 × (18:1 cis 9 / (18:0 + 18:1 cis 9))].

Statistical Analysis

Statistical analyses were performed using the PROC MIXED procedure in SAS and the PROC GLIMMIX procedure for determining the distribution of USDA QG (SAS Inst., Inc., Cary, NC). The experimental design was a randomized complete block design with steer as the experimental unit. The statistical model used was: $Y_{ij} = \mu + B_i + y_j + e_{ij}$, where B_i = sire breed as a fixed effect, and the random effect of y_j = year, and e_{ij} = random error. The statistical model used for WBSF was: $Y_{ijk} = \mu + B_i + P_j + BP_{ij} + y_k + e_{ijk}$, where P_j = postmortem aging and BP_{ij} = sire breed × postmortem aging as fixed effects. The LSMEANS and PDIFF statements were used to record treatment least square mean estimates, standard errors, and distinguish differences between the treatment levels. When significant, initial BW, HCW, and chilled side weight were used as covariates for the feedlot performance data, carcass data, and cutout data, respectively. A significance of fixed effects and covariates was established at $P \leq 0.05$ and tendencies are discussed at $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Feedlot Performance

Before adjustment, Angus and Jersey sired steer calves (222 and 225 kg, respectively) had a greater ($P \leq 0.01$) initial BW (SD = 31.4 kg) compared with SimAngus and Wagyu sired steer calves (198 and 194 kg, respectively). Therefore, the feedlot performance measures for steers were adjusted to a similar initial BW (210 kg; Table 2) using a linear covariate. The adjusted receiving age of purebred Jersey steer calves was greater ($P \leq 0.01$) compared with the receiving age of crossbred steer calves at the initiation of the present study.

Over the course of the feeding trial, the ADG of crossbred Jersey steers was greater ($P \leq 0.01$) compared with purebred Jersey steers, and SimAngus sired steers tended to have a greater ($P = 0.06$) ADG compared with Wagyu sired steers. Angus sired steers had a greater average daily dry matter intake (DMI; $P \leq 0.01$) compared with Wagyu and Jersey sired steers, while SimAngus sired steers had a greater ($P \leq 0.03$) average daily DMI compared with Jersey sired steers and tended to have a greater ($P = 0.08$) average daily DMI compared with Wagyu sired steers. Wagyu sired steers were more feed efficient ($P \leq 0.01$), and SimAngus sired steers tended ($P = 0.09$) to be more feed efficient, compared with Jersey sired steers. Purebred Jersey steers required more ($P \leq 0.01$) days on feed compared with crossbred Jersey steers, and Wagyu sired steer required more days on feed ($P \leq 0.02$) compared with Angus sired steers, before being removed from the feeding trial for harvest. As a result of both a greater age

Table 2. Effect of terminal sire breed on the feedlot performance of purebred and crossbred Jersey steers adjusted to a similar initial body weight (210 kg)

Item	Sire breed				SEM*	P value
	Jersey (n = 21)	Angus (n = 9)	SimAngus (n = 10)	Wagyu (n = 15)		
Initial weight, kg	222 ^d	224 ^d	198 ^e	194 ^e	9.9	0.01
Age at receiving, d [†]	257 ^d	227 ^e	212 ^e	231 ^e	10.1	0.01
Average daily gain, kg/d	0.85 ^e	1.05 ^d	1.08 ^d	0.97 ^d	0.0444	0.01
Daily dry matter intake, kg/d [†]	6.67 ^f	7.72 ^d	7.35 ^{de}	6.80 ^{ef}	0.267	0.01
Total dry matter intake, kg [‡]	2,316	2,335	2,304	2,217	170.4	0.62
Gain:feed, kg/kg [‡]	0.123 ^b	0.133 ^{ab}	0.135 ^{ab}	0.142 ^a	0.0059	0.03
Days on feed, d [†]	346 ^d	304 ^f	314 ^{ef}	331 ^e	17.0	0.01
Age at harvest, d	602 ^d	533 ^e	539 ^e	562 ^e	21.5	0.01
Off-test weight, kg [‡]	499 ^e	531 ^d	548 ^d	532 ^d	15.4	0.01

^{a-c}Sire breed lsmean estimates within a row with a different superscript differ ($P \leq 0.05$).

^{d-f}Sire breed lsmean estimates within a row with a different superscript differ ($P \leq 0.01$).

*The reported standard error of the mean is the greatest between the sire breeds.

[†]Variables were standardized to a common weight (210 kg) using initial weight as a linear covariate.

at feedlot entry and number of days spent on feed, purebred Jersey steers were older ($P \leq 0.01$) compared with crossbred Jersey steers at the time of harvest, while Wagyu sired steers tended ($P = 0.09$) to be older than Angus sired steers. Even with a greater number of days spent on feed by purebred Jersey steers compared with crossbred Jersey steers, facility constraints required purebred Jersey steers to be removed before reaching the targeted BW endpoint, resulting in greater ($P \leq 0.01$) off-test BW for crossbred Jersey steers compared with purebred Jersey steers.

A lesser ADG from Jersey cattle or Jersey sired cattle compared with other breeds of cattle offered concentrate based diets has been commonly reported (Cole et al., 1964; Smith et al., 1976; Young et al., 1978; Lehmukuler and Ramos, 2008). Jersey sired steers have been reported to consume less feed and be less feed efficient compared with other breeds of cattle, including Simmental and Angus sired steers from Hereford or Angus cows (Smith et al., 1976). Retallick et al. (2013) compared Angus, Simmental, and SimAngus crossbred steers and found no difference in DMI of steers, but the influence of Simmental genetics tended to increase ADG and improve feed efficiency compared with the influence of Angus genetics. Smith et al. (1976) also reported a greater ADG of steers from Simmental sires compared with Angus sires. Similar feedlot performance results between Angus and SimAngus sired steers in the present study may be the result of random sire sampling within and across breeds, as no attempt was made to identify bulls reflective of sire breed averages. Radunz et al. (2009) compared Angus and Black Wagyu sired cattle from Angus cows and reported a greater ADG and DMI from Angus sired cattle compared with Wagyu sired cattle; however, Wagyu sired cattle were more feed efficient compared with Angus sired cattle. The results of the present study for ADG and feed efficiency numerically follow the same trend as reported by Radunz et al. (2009). However, the results of the present study are not in agreement with significant differences for ADG and feed efficiency between Angus and Wagyu sired cattle. Additionally, in contrast to Radunz et al. (2009), Red Wagyu or “Akaushi” sires from the Kumamoto lineage were used in the present study rather than Black Wagyu sires from the Tajima lineage. Black Wagyu cattle typically have a slower rate of gain, but deposit more marbling when compared with Red Wagyu cattle (Sasaki et al., 2006; Motoyama et al., 2016), which may contribute to the observed differences between studies.

Carcass Characteristics

Carcass characteristics from purebred and crossbred Jersey steers were adjusted to a similar HCW (319 kg) to compare carcass measures consistently across sire breeds (Table 3). Final live BW before harvest was not different ($P = 0.36$) between steers; however, crossbred Jersey steers had a greater ($P \leq 0.01$) dressing percentage compared with purebred Jersey steers. Before adjustment, Angus and SimAngus sired steers (334 and 332 kg, respectively) had a greater ($P \leq 0.01$) HCW (SD = 29.6 kg) compared with Wagyu and Jersey sired steers (317 and 304 kg, respectively). Angus sired steers produced carcasses with a greater ($P \leq 0.01$) BFT compared with carcasses from SimAngus, Wagyu, and Jersey sired steers. Longissimus muscle area (LMA) was not different ($P = 0.12$) between carcasses from the different sire breeds. However, the LMA:HCW ratio tended ($P = 0.09$) to be affected by sire breed, with Wagyu sired carcasses having a greater LMA:HCW ratio compared with Jersey sired carcasses. Jersey sired steers had the greatest ($P \leq 0.01$) KF percentage (7.9%), followed by Wagyu and SimAngus sired steers (6.4%), and lastly Angus sired steers (5.3%). There were no differences in calculated USDA YG ($P = 0.16$) and calculated percent BCTRC ($P = 0.16$) for carcasses from the different sire breeds. Carcass maturity scores were also similar ($P = 0.25$), as all carcasses were young cattle representing “A maturity.” Carcasses from Angus and Wagyu sired steers had a greater ($P \leq 0.03$) marbling score compared with carcasses from Jersey sired steers. On average, Angus sired steers had a slightly abundant degree of marbling, Wagyu and SimAngus sired steers had a moderate degree of marbling, while Jersey sired steers had a modest degree of marbling. This resulted in carcasses from Angus sired steers receiving a significantly greater ($P \leq 0.04$) USDA QG score compared with carcasses from Jersey sired steers. Average USDA QG was Low Prime for carcasses from Angus sired steers, High Choice for carcasses from Wagyu and SimAngus sired steers, and Average Choice for carcasses from Jersey sired steers. The distribution of USDA QG for steers in the present study is presented in Table 3.

In accordance with the feedlot performance results reported in the present study, Jersey sired steer data are typically reported with a lesser HCW compared with other sire breeds due to a lesser ADG and mature frame size when offered a concentrate based diet in a feedlot setting (Cole et al., 1964; Koch et al., 1976; Koch and Dikeman, 1977; Young et al., 1978; Lehmkuhler and Ramos, 2008).

Table 3. Effect of sire breed on carcass characteristics of purebred and crossbred Jersey steers adjusted to a similar hot carcass weight (319 kg)

Item	Sire breed				SEM*	P value
	Jersey (n = 20)	Angus (n = 9)	SimAngus (n = 10)	Wagyu (n = 15)		
Final weight, kg	496	520	515	502	17.8	0.36
Hot carcass weight, kg	304 ^b	334 ^a	332 ^a	317 ^{ab}	11.8	0.02
Dressing percent, %	61.24 ^e	64.19 ^d	63.93 ^d	63.20 ^d	0.428	0.01
Fat thickness, cm	0.86 ^e	1.37 ^d	1.04 ^e	0.97 ^e	0.160	0.01
Longissimus muscle area, cm ² †	70.3	73.6	73.6	76.4	3.72	0.12
Kidney fat, %	7.89 ^d	5.28 ^f	6.48 ^e	6.43 ^e	0.451	0.01
Calculated Yield grade ‡	4.06	3.88	4.01	3.59	0.233	0.16
Calculated BCTRC, %	47.39	47.77	47.48	48.47	0.541	0.16
Marbling score [§]	586 ^b	745 ^a	651 ^{ab}	687 ^a	63.0	0.03
Quality grade¶	11.4 ^b	13.0 ^a	12.0 ^{ab}	12.3 ^{ab}	0.631	0.04
% Prime +	0.0	11.1	0.0	13.3	0.105	1.00
% Prime o	5.0	33.3	10.0	13.3	0.157	0.30
% Prime –	10.0	22.2	40.0	20.0	0.139	0.35
% Choice +	25.0	33.3	20.0	26.7	0.157	0.93
% Choice o	35.0	0.0	10.0	13.3	0.107	0.38
% Choice –	25.0	0.0	10.0	13.3	0.010	0.74
% Select +	0.0	0.0	10.0	0.0	0.095	1.00
Lean color						
L*	41.4 ^f	46.9 ^d	43.8 ^e	44.7 ^e	0.748	0.01
a*	25.1 ^f	25.8 ^{ef}	26.9 ^d	26.4 ^{de}	0.416	0.01
b*	8.5	10.0	9.7	10.9	0.961	0.12
Fat color						
L*	71.7	73.0	73.7	72.2	1.255	0.29
a*	13.7	14.7	12.4	14.1	0.978	0.36
b*	18.3 ^e	21.3 ^d	18.1 ^e	18.6 ^e	0.735	0.01

^{a-c}Sire breed lsmean estimates within a row with a different superscript differ ($P \leq 0.05$).

^{d-f}Sire breed lsmean estimates within a row with a different superscript differ ($P \leq 0.01$).

*The reported standard error of the mean is the greatest between the sire breeds.

†Variables were standardized to a common weight (319 kg) using hot carcass weight as a linear covariate.

‡Yield grade = $2.5 + (2.5 \times (\text{fat thickness} / 2.54)) + (0.2 \times \text{kidney, pelvic, heart fat}) + (0.0038 \times (\text{hot carcass weight} / 0.453592)) - (0.32 \times (\text{Longissimus muscle area} / 6.4516))$.

||BCTRC (Boneless closely trimmed retail cuts) = $51.34 - (2.28 \times (\text{fat thickness})) - (0.462 \times \% \text{kidney fat}) - (0.02 \times (\text{hot carcass weight})) + (0.1147 \times (\text{Longissimus muscle area}))$.

§Marbling score is based on a numeric scale: 500–599 = modest, 600–699 = moderate, 700–799 = slightly abundant.

¶Quality grade is based on a numeric scale: 11 = Average Choice, 12 = High Choice, 13 = Low Prime.

Purebred and Jersey sired steers typically have lesser dressing percentages (Cole et al., 1964; Koch et al., 1976; Koch and Dikeman, 1977; Lehmkuhler and Ramos, 2008) compared with steers from other sire breeds, which also contributes to their lesser HCW. The lesser dressing percentages for purebred Jersey steers could be due to a combination of factors, such as a lesser weight of muscle and the potential for loss of internal (kidney) fat weight during evisceration or final trimming relative to other breeds of cattle.

Angus sired steers had the greatest BFT when compared with the other sire breeds in this study. This is in agreement with previous literature reports

(Cole et al., 1964; Charles and Johnson, 1976; Kempster et al., 1976; Koch et al., 1976; Pitchford et al., 2002) that describe steers with Angus and Hereford genetics as having greater deposits of subcutaneous fat relative to other breeds of cattle. Radunz et al. (2009) reported a greater fat thickness at the 6th rib, but not at the 12th rib of carcasses from Angus sired cattle when compared with Wagyu sired cattle. Also in agreement with the results from the present study, Retallick et al. (2013) reported a greater BFT for Angus steers compared with Simmental and SimAngus steers. Interestingly, Jersey cattle appear to have a very different pattern of carcass fat distribution compared with Angus

cattle. In the present study, Jersey sired steers had a lesser thickness of backfat and a greater percentage of kidney fat, while Angus sired steers had a greater thickness of backfat and a lesser percentage of kidney fat. Previous reports by [Cole et al. \(1964\)](#) and [Koch et al. \(1976\)](#) agree with a greater percentage of kidney fat in purebred Jersey and Jersey sired steer carcasses relative to other breeds of cattle. [Kempster et al. \(1976\)](#) also reported crossbred Angus steers to have a numerically lesser percentage of kidney fat relative to steers from 15 other breed \times diet groups. Jersey sired steers have previously demonstrated their ability to deposit marbling at similar levels to cattle breeds, such as Angus and Wagyu, which are commonly known to produce highly marbled beef ([Pitchford et al., 2002](#)). [Koch et al. \(1976\)](#) reported that Jersey sired steers had a numerically greater percentage of fat in the longissimus muscle (8.2%) compared with other sire breeds, such as Angus (7.6%) and Hereford (5.5%) adjusted to a similar HCW. Purebred Jersey steers have been reported to deposit small to modest amounts of marbling when finished on a high concentrate diet ([Lehmkuhler and Ramos, 2008](#); [Arnett et al., 2012](#)). Results from the current study more closely align with the marbling scores reported more recently by [Lehmkuhler and Ramos \(2008\)](#) and [Arnett et al. \(2012\)](#), with purebred Jersey steer carcasses averaging a modest degree of marbling in the present study. In disagreement with some of the previous reports mentioned, purebred Jersey steers had a lesser marbling score compared with the other sire breeds used in the present study. Overall, there were significant differences in the distribution of fat on the carcasses from steers sired by the different breeds of cattle in the present study.

Purebred Jersey steers had similar LMA compared with the crossbred Jersey steers sired by the beef breeds investigated. [Lehmkuhler and Ramos \(2008\)](#) reported smaller LMA from purebred Jersey steers when compared with Holstein steers; however, purebred Jersey steers had a greater LMA:HCW ratio compared with Holstein steers. In agreement with the expectation that Jersey cattle are lighter muscled than other breeds of cattle, [Cole et al. \(1964\)](#) reported that Jersey steers had a lesser LMA and round circumference compared with beef breeds of cattle. [Koch et al. \(1976\)](#) and [Young et al. \(1978\)](#) reported that Jersey sired steers had lesser LMA compared with South Devon, Simmental, Limousin, and Charolais sired crossbred steers. [Radunz et al. \(2009\)](#) reported that there was a tendency for Wagyu sired cattle to have greater LMA compared with Angus sired cattle. [Retallick et al.](#)

(2013) reported SimAngus steers to have greater LMA compared with Angus steers due to the influence of Simmental genetics. The lack of significant sire breed differences for the LMA in the present study may reflect the randomness of sire sampling within and across the sire breeds evaluated, but may also be due to the large amount of variation in the LMA from steers in the present study (SD = 8.71 cm²).

Lean color of the longissimus muscle was lighter (greater L* value; $P \leq 0.01$) for Angus sired steers, followed by Wagyu and SimAngus sired steers, and lastly Jersey sired steers had the darkest colored lean. Lean lightness (L*) values followed a similar pattern as marbling score, with carcasses from Angus sired cattle having a greater CIELAB L* value, carcasses from SimAngus and Wagyu sired cattle being intermediate, and Jersey sired steer carcasses having the lowest CIELAB L* value. There was a significant ($P \leq 0.01$; $r = 0.52$) positive correlation between lean CIELAB L* and marbling, demonstrating lean color lightness is influenced by the degree of marbling present within the muscle. [Wulf et al. \(1999\)](#) also reported a weaker ($r = 0.26$), but significant correlation between lean CIELAB L* values and marbling score. SimAngus sired steers had a redder (greater a* value; $P \leq 0.01$) colored lean compared with Angus and Jersey sired steers, while Wagyu sired steers had a redder colored lean compared with Jersey sired steers. There were no sire breed differences for lean CIELAB b* values ($P = 0.12$), fat CIELAB L* values ($P = 0.29$), and fat CIELAB a* values ($P = 0.36$). Dairy cattle have previously been reported to have lesser colorimeter values (L*, a*, b*) when compared with native *Bos taurus* and *Bos indicus* cattle ([Page et al., 2001](#)), which is in agreement with the findings in the present study. Interestingly, Angus sired steers produced carcasses with a more yellow (greater b* value; $P \leq 0.01$) carcass fat when compared with carcasses from SimAngus, Wagyu, and Jersey sired steers. Jersey cattle are a breed of cattle commonly known to produce yellow carcass fat due to the greater concentrations of β -carotene in their fat ([Kruk et al., 1998](#)). [Tian et al. \(2010\)](#) reported Jersey cattle have a higher frequency of the AA genotype for the β -carotene-9, 10-dioxygenase (BCO2) gene, which leads to the loss of enzyme function and a greater accumulation of β -carotene in the carcass fat that results in the yellow fat color. Therefore, Angus sired steers in the present study may have had greater concentrations of β -carotene deposited in their carcass fat relative to steers from the other sire breeds due to their BCO2 allele frequency.

Carcass Cutout Distribution

The effect of sire breed on the carcass cutout distribution comparing purebred Jersey steers and crossbred Jersey steers is compared at a similar chilled side weight (155 kg; [Table 4](#)). Before adjustment, Angus and SimAngus sired steers (162 and 161 kg, respectively) had a greater ($P \leq 0.01$) chilled side weight (SD = 14.1 kg) compared with Wagyu and Jersey sired steers (154 and 148 kg, respectively). SimAngus and Wagyu sired steer carcasses had a greater ($P \leq 0.02$) weight of total red meat (retail cuts and lean trim) compared with Jersey sired steer carcasses, while Wagyu sired steer carcasses tended ($P = 0.07$) to have a greater weight of total red meat compared with Angus sired steer carcasses. Wagyu sired steer carcasses had a greater retail yield ($P \leq 0.01$) and total red meat yield ($P \leq 0.01$) compared with Angus and Jersey sired steer carcasses, while SimAngus sired steer carcasses had a greater retail yield ($P \leq 0.01$) and total red meat yield ($P \leq 0.03$) compared with Jersey sired steer carcasses. There were no differences in bone yield ($P = 0.37$); however, carcasses from Angus and Jersey sired steers tended ($P = 0.07$) to have a greater fat yield compared with carcasses from Wagyu sired steers. SimAngus sired steer carcasses had a greater ($P \leq 0.05$) weight of retail cuts in the chuck compared with Jersey sired steer carcasses, which was the primary result of a greater ($P \leq 0.02$) shoulder clod weight and the accumulation of small, nonsignificant increased weights of other muscles in the chuck for SimAngus sired steer carcasses relative to Jersey sired steer carcasses. Wagyu sired steer carcasses tended to have a greater weight of retail cuts in the chuck ($P = 0.06$) and greater clod weight ($P = 0.07$) compared with Jersey sired steer carcasses. Angus sired steer carcasses had a greater ($P \leq 0.01$) weight of brisket contributing to their carcass weight compared with carcasses from the other sire breeds. There was no difference ($P = 0.81$) in the weight of retail cuts in the rib primal between carcasses from the different sire breeds. Wagyu sired steer carcasses had a greater ($P \leq 0.01$) weight of retail cuts in the loin primal when compared with carcasses from the other sire breeds. Greater loin primal weight was influenced by Wagyu sired steer carcasses having a greater weight from the striploin ($P \leq 0.01$) and bottom sirloin tri-tip ($P \leq 0.03$) compared with the other sire breeds and a greater weight from the short loin ($P \leq 0.01$) and top sirloin butt ($P \leq 0.01$), compared with Angus and Jersey sired steer carcasses. SimAngus sired steer carcasses tended ($P = 0.06$) to have a

greater short loin weight compared with Jersey sired steer carcasses. Wagyu and SimAngus sired steer carcasses had a greater top sirloin butt cap ($P \leq 0.04$) weight compared with Angus and Jersey sired steer carcasses. There were no sire breed differences ($P = 0.21$) in the weight of the flank steak; however, for SimAngus sired steer carcasses, the outside skirt steak had a greater ($P \leq 0.03$) weight compared with the other sire breeds. In the round primal, Wagyu sired steer carcasses had a greater ($P \leq 0.01$) weight of retail cuts in the round compared with Jersey and Angus sired steer carcasses and tended ($P = 0.08$) to have a greater weight of retail cuts in the round compared with SimAngus sired steer carcasses. SimAngus sired steer carcasses had a greater ($P \leq 0.01$) weight of retail cuts in the round compared with Angus sired steer carcasses, while Jersey sired steer carcasses tended ($P = 0.06$) to have a greater weight of retail cuts in the round compared with Angus sired steer carcasses. Wagyu sired steer carcasses had a greater weight for the top round ($P \leq 0.01$) and bottom round flat ($P \leq 0.01$) compared with the other sire breeds, whereas, SimAngus sired steer carcasses tended ($P = 0.06$) to have a greater weight for the top round compared with Angus sired steer carcasses. SimAngus sired steer carcasses had a greater ($P \leq 0.02$) weight for the bottom eye of round compared with Angus and Jersey sired steer carcasses and tended ($P = 0.10$) to have a greater weight for the bottom eye of round compared with Wagyu sired steer carcasses. There was no difference in the weight of total lean trim ($P = 0.42$) and total bone ($P = 0.57$) between carcasses from the different sire breeds. However, carcasses from crossbred Jersey steers had a greater ($P \leq 0.05$) weight of lean trim from the hind quarter compared with purebred Jersey steer carcasses. Angus sired steer carcasses had the greatest ($P \leq 0.02$) weight of trimmed fat from the front quarter, while Jersey sired steer carcasses had the greatest ($P \leq 0.03$) weight of trimmed fat from the hind quarter due to a greater ($P \leq 0.01$) weight of kidney fat compared with carcasses from the other sire breeds. As a result, total fat trim was greater ($P \leq 0.04$) for Angus and Jersey sired steer carcasses compared with Wagyu sired steer carcasses.

[Koch and Dikeman \(1977\)](#) reported the carcass cutout composition of implanted steers sired by Hereford, Angus, Jersey, South Devon, Limousin, Charolais, and Simmental bulls mated to Hereford and Angus cows with a similar days on feed endpoint. [Koch and Dikeman \(1977\)](#) reported a similar carcass cutout percentage between crossbred Angus and Jersey sired steers for the chuck (19.6%), rib

Table 4. Effect of sire breed on the distribution of carcass weight into retail cuts from purebred and cross-bred Jersey steers adjusted to a similar chilled carcass side weight (154 kg)

Item	Sire breed				SEM*	P value
	Jersey (n = 20)	Angus (n = 9)	SimAngus (n = 10)	Wagyu (n = 15)		
Side weight, kg	147.6 ^b	162.1 ^a	161.1 ^a	153.8 ^{ab}	5.59	0.02
Total red meat, kg ^{†,‡}	83.3 ^b	84.8 ^{ab}	87.8 ^a	88.6 ^a	3.03	0.01
Retail yield, %	33.67 ^f	34.42 ^{ef}	35.72 ^{de}	36.28 ^d	1.058	0.01
Total red meat yield, % [‡]	54.03 ^f	54.67 ^{ef}	56.55 ^{de}	57.25 ^d	2.016	0.01
Fat yield, %	24.08	24.45	22.86	21.47	2.238	0.07
Bone yield, %	20.96	20.00	19.97	21.12	0.684	0.37
Chuck, kg [†]	12.61 ^b	13.42 ^{ab}	14.33 ^a	13.64 ^{ab}	0.986	0.05
Shoulder clod, kg [†]	3.47 ^b	4.08 ^{ab}	4.60 ^a	4.00 ^{ab}	0.580	0.02
Top blade, kg [†]	1.39	1.45	1.75	1.52	0.129	0.12
Clod teres major, kg	0.43	0.42	0.39	0.49	0.059	0.42
Chuck tender, kg [†]	0.95	0.96	0.95	1.03	0.063	0.16
Boneless chuck roll 2" × 2" tail, kg [†]	6.36	6.52	6.70	6.59	0.357	0.68
Brisket						
Brisket, kg [†]	4.69 ^e	5.71 ^d	4.83 ^e	4.51 ^e	0.292	0.01
Rib, kg [†]	6.47	6.60	6.54	6.67	0.197	0.81
Ribeye roll, kg [†]	4.78	4.99	4.94	4.98	0.172	0.67
Back-ribs, kg	1.66	1.62	1.63	1.66	0.115	0.97
Plate						
Skirt steak-inside, kg [†]	0.58	0.65	0.66	0.53	0.082	0.42
Skirt steak-outside, kg [†]	0.38 ^b	0.36 ^b	0.48 ^a	0.35 ^b	0.040	0.03
Loin, kg [†]	10.54 ^e	10.64 ^e	10.98 ^e	12.05 ^d	0.334	0.01
Short loin, kg [†]	7.77 ^e	7.98 ^e	8.22 ^{de}	8.57 ^d	0.243	0.01
Striploin 1" tail, kg [†]	4.09 ^e	4.29 ^e	4.28 ^e	4.74 ^d	0.214	0.01
Tenderloin tail, kg [†]	0.89	0.83	0.95	0.94	0.065	0.14
Tenderloin butt, kg	0.96	1.00	1.06	1.01	0.058	0.58
Top sirloin butt (boneless), kg [†]	2.76 ^b	2.65 ^b	2.90 ^{ab}	3.22 ^a	0.164	0.01
Top sirloin butt cap, kg [†]	0.68 ^b	0.64 ^b	0.73 ^a	0.80 ^a	0.052	0.04
Bottom sirloin ball tip, kg	0.39	0.61	0.54	0.56	0.199	0.31
Bottom sirloin tri-tip, kg [†]	0.70 ^b	0.68 ^b	0.70 ^b	0.83 ^a	0.607	0.03
Flank						
Flank steak, kg [†]	0.66	0.63	0.70	0.66	0.026	0.21
Round, kg [†]	16.12 ^{ef}	15.06 ^f	16.73 ^{de}	17.66 ^d	0.546	0.01
Knuckle (peeled), kg [†]	3.76	3.36	3.85	3.97	0.200	0.11
Inside round (boneless), kg [†]	6.86 ^e	6.51 ^e	7.03 ^e	7.68 ^d	0.271	0.01
Bottom round eye, kg [†]	1.50 ^b	1.48 ^b	1.70 ^a	1.59 ^{ab}	0.099	0.02
Bottom round flat, kg [†]	3.99 ^e	4.13 ^e	4.13 ^e	4.44 ^d	0.173	0.01
Lean trim—fore, kg [†]	21.31	20.23	22.13	21.36	1.128	0.28
Lean trim—hind, kg	9.46 ^b	11.59 ^a	10.66 ^a	10.70 ^a	0.642	0.05
Total lean trim, kg [†]	31.05	31.56	32.51	32.14	1.412	0.42
Fat trim—fore, kg [†]	12.58 ^b	15.85 ^a	12.78 ^b	11.67 ^b	2.061	0.02
Fat trim—hind, kg ^{†,§}	25.40 ^a	21.70 ^b	22.04 ^b	21.82 ^b	1.519	0.03
Kidney fat, kg [†]	12.19 ^d	7.88 ^e	9.78 ^e	9.97 ^e	0.626	0.01
Total fat trim, kg [†]	37.98 ^a	37.47 ^a	34.85 ^{ab}	33.41 ^b	3.182	0.04
Bone—fore, kg [†]	20.30	19.25	19.61	20.13	1.123	0.89
Bone—hind, kg [†]	11.80	11.79	11.42	12.49	0.786	0.68
Total bone, kg [†]	32.11	31.01	31.04	32.59	1.126	0.57

^{a-c}Sire breed lsmean estimates within a row with a different superscript differ ($P \leq 0.05$).

^{d-f}Sire breed lsmean estimates within a row with a different superscript differ ($P \leq 0.01$).

*The reported standard error of the mean is the greatest between the sire breeds.

[†]Variables were standardized to a common weight (154 kg) using chilled carcass side weight as a linear covariate.

[‡]Total red meat yield is the sum of the boneless closely trimmed retail cuts and lean trimmings.

^{||}Retail yield refers to boneless closely trimmed retail cuts.

[§]Fat trim from the hind quarter includes the kidney fat.

(6.2%), loin (9.7%), and round (16.3% and 15.5%) primals; however, these percentages were less when compared with Simmental sired steers (21.0%, 6.4%, 10.3%, and 18.1%, respectively). Crossbred Simmental and Angus sired steers had greater percentages of retail product from the brisket (2.7%) compared with crossbred Jersey sired steers (2.4%). Overall, Koch and Dikeman (1977) reported greater retail yield from steers with Continental sire influence (Simmental, 68.9%) compared with British sire influence (Angus, 64.4% and Jersey, 63.4%), while the fat trim yield was greater from Angus and Jersey sired steers (24.5%) compared with Simmental sired steers (18.1%), with all steers having a relatively similar percentage of total bone yield (11.3%–12.9%). Results of the present study are in agreement with the results of Koch and Dikeman (1977) for the percentage of retail product in the chuck, brisket, rib, loin, and round between Angus and Jersey sired steers. However, cutout data from the SimAngus sired steers in the present study did not match the retail cut percentages reported for Simmental steers from the Koch and Dikeman (1977) study. The lack of differences observed between SimAngus sired steers in our study versus the large differences observed from Simmental sired steers in the Koch and Dikeman (1977) study may be due to the influence of Angus genetics in the SimAngus cross. Overall, the distribution of retail products across sire breeds in the present study differed much less than the sire breed effects reported by Koch and Dikeman (1977); however, crossbreeding appeared to improve carcass cutout composition when compared with purebred Jersey steers.

Comparing the cutability and carcass cutout distribution of Wagyu sired steers to previous literature is difficult due to a limited number of literature reports, which is partially due to the Wagyu breed being relatively new to the United States and because carcass retail yield is more likely to be estimated from established predictor equations to save time and money. However, Greenwood et al. (2006) previously reported retail yield comparisons between Wagyu and Piedmontese sired steers and heifers from Hereford cows. Wagyu and Piedmontese sires reported by Greenwood et al. (2006) were selected based on a combination of muscling and marbling, with no mention of Myostatin genotype for the Piedmontese sires used. Wagyu sired cattle produced carcasses with a lesser HCW, dressing percentage, and LMA, but Wagyu sired cattle had a greater BFT and marbling score when compared with Piedmontese sired cattle (Greenwood et al., 2006). Wagyu sired cattle also produced

a lesser carcass retail yield, with a similar bone yield, and greater fat trim yield when compared with Piedmontese sired cattle (Greenwood et al., 2006). Wheeler et al. (2004) reported estimates for retail yield, fat yield, and bone yield of implanted steers sired by Hereford, Angus, Norwegian Red, Swedish Red and White, Holstein, and Wagyu bulls mated to Hereford, Angus, and MarcIII cows at different adjusted endpoints (age, HCW, BFT, marbling, percent fat trim). At a similar hot carcass weight (356 kg), Wagyu sired steer carcasses had a similar weight of retail product, fat, and bone compared with Angus sired steer carcasses. Results from the present study agree with those of Wheeler et al. (2004) that Wagyu sired steer carcasses have a similar bone yield compared with Angus sired steer carcasses. However, we noticed a tendency for Wagyu sired steer carcasses to have a lesser fat yield and a greater retail yield when compared with Angus sired steer carcasses. Based upon the results of the present study and the reviewed literature, Angus and Jersey sired steers are expected to have a similar retail yield and fat yield, with Jersey sired cattle having a slightly greater bone yield. SimAngus and Wagyu sired steers are expected to have a greater retail yield, lesser fat yield, and similar bone yield compared with Jersey sired steers. Review of the literature indicates sire breeds with more continental influence, such as Simmental, Charolais, Limousin, and Piedmontese, may have an even greater retail yield, lesser fat yield, and similar bone yield compared with SimAngus and Wagyu sired steers. Overall, and similar to findings reported by Mukhoty and Berg (1971) and Koch and Dikeman (1977), the distribution of muscle in retail cuts did not vary greatly by sire breed in the present study. However, the distribution of fat deposition in the carcass appears more variable by breed as demonstrated by differences in BFT, percent KF, and marbling score (Charles and Johnson, 1976; Kempster et al., 1976).

Warner-Bratzler Shear Force

The effects of sire breed and postmortem aging on the WBSF of ribeye steaks from purebred and crossbred Jersey steers are presented in Figure 1. There was no difference ($P = 0.96$) for the interaction between sire breed and postmortem aging period. Ribeye steaks from SimAngus and Wagyu sired steers (2.48 and 2.39 kg, respectively) had a lesser ($P \leq 0.01$) WBSF value compared with ribeye steaks from Angus and Jersey sired steers (2.76 and 2.71 kg, respectively). Postmortem aging improved

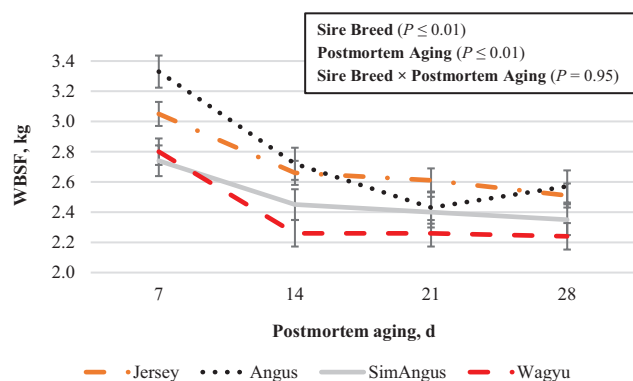


Figure 1. Effect of sire breed and postmortem aging period on the Warner-Bratzler shear force of the longissimus muscle from purebred and crossbred Jersey steers. SimAngus and Wagyu sired steers produced more ($P \leq 0.01$) tender steaks compared to Angus and Jersey sired steers. Postmortem aging improved ($P \leq 0.01$) steak tenderness from 7 to 14 days. The standard error of the mean (SEM) for the interaction between sire breed and postmortem aging was 0.213 kg.

tenderness, with a lesser ($P \leq 0.01$) WBSF value for ribeye steaks aged 14 d compared with 7 d (2.53 vs. 2.98 kg, respectively). Aging steaks until 21 and 28 d (2.42 kg) postmortem did not result in significant ($P > 0.37$) improvements in tenderness when compared with postmortem aging at 14 d. The USDA AMS (ASTM, 2011) maintains specific standards for “tender” (<4.4 kg WBSF) and “very tender” (<3.9 kg WBSF) label claims made for steaks. As demonstrated by Figure 1, on average, ribeye steaks from the steers in the present study, regardless of sire breed, would qualify for USDA very tender certification. Steaks from 85.2% of the cattle in the present study would qualify for the USDA AMS labeling claim “very tender” after 7 d of postmortem aging and 96.3% would qualify after 14 d of postmortem aging.

Cole et al. (1964) reported purebred Jersey loin steaks had the lowest WBSF value when compared with many different breeds of cattle (Hereford, Angus, Brahman and cross, Santa Gertrudis, Holstein, and Charolais cross), but were not significantly different from Hereford, Brahman cross, or Holstein steers. Arnett et al. (2012) investigated the WBSF value of strip loin steaks from purebred Jersey steers offered either a high forage (24%) or low forage (12%) finishing ration compared with commodity beef strip loin steaks when aged for 18 d postmortem. Results from Arnett et al. (2012) demonstrated a greater WBSF value from the commodity beef strip loin steaks (3.12 kg) compared with strip loin steaks from the purebred Jersey steers (2.62 and 2.64 kg). Bumsted et al. (2014) compared the WBSF value of strip loin steaks from Limousin \times Jersey steers to Certified Angus Beef strip loin steaks. Certified Angus Beef strip loin steaks had a

lesser WBSF value compared with strip loin steaks from Limousin \times Jersey steers (Bumsted et al., 2014). In disagreement with the results of the present study, Radunz et al. (2009) reported a similar WBSF value of strip loin steaks from Angus and Wagyu sired cattle at 3 d (4.3 kg) and 14 d (3.2 and 3.1 kg, for Angus and Wagyu sired cattle, respectively) of postmortem aging. Overall, data from the present study and previously published literature indicate purebred and crossbred Jersey steers can produce steaks that are very tender in comparison to other breeds of cattle and the beef industry average.

Longissimus Fatty Acid Composition

The fatty acid composition of purebred Jersey and crossbred Jersey steers were evaluated for the effect of sire breed (Table 5). Total lipid percentage tended ($P = 0.10$) to be affected by sire breed, with muscle from Angus sired steers having a numerically greater percentage compared with muscle from Jersey sired steers. Muscle from SimAngus and Angus sired steers tended ($P = 0.06$) to have a greater percentage of palmitic acid (16:0) compared with Jersey sired steers. The percentage of myristic acid (14:0) tended ($P = 0.10$) to be affected by sire breed, with muscle from Wagyu sired steers having a numerically greater percentage compared with muscle from Jersey sired steers. As a direct result, Wagyu sired steers tended ($P = 0.09$) to have the lowest desaturase (14) index compared with the other sire breeds. Linoleic acid (18:2) percentage tended ($P = 0.06$) to be affected by sire breed, with muscle from Jersey sired steers having a numerically greater percentage of 18:2 compared with muscle from Angus sired steers. As a result of a greater percentage of 18:2, Jersey sired steers had a greater ($P \leq 0.04$) percentage of polyunsaturated fatty acids (PUFA) in their muscle and a greater ($P \leq 0.02$) ratio of PUFA to saturated fatty acids (SFA) compared with the muscle of Angus sired steers. The percentage of oleic acid (18:1cis9; $r = 0.32$; $P \leq 0.02$), linoleic acid (18:2; $r = -0.60$; $P \leq 0.01$), monounsaturated fatty acid (MUFA; $r = 0.34$; $P \leq 0.02$), PUFA ($r = -0.59$; $P \leq 0.01$), and PUFA:SFA ($r = -0.50$; $P \leq 0.01$) were significantly correlated with the percentage of total lipid found in the muscle. When the fatty acid composition was adjusted to a similar total lipid percentage, there were no significant ($P > 0.13$) sire breed effects observed for the percentage of 18:1cis9, 18:2, MUFA, PUFA, and the PUFA:SFA ratio.

Jiang et al. (2013) reported the total lipid percentage (6.21%) and fatty acid composition of

Table 5. Effect of sire breed on the fatty acid composition (%) of the longissimus muscle from purebred and crossbred Jersey steers

Item	Sire breed				SEM*	P value
	Jersey (n = 20)	Angus (n = 9)	SimAngus (n = 10)	Wagyu (n = 15)		
Total fatty acids, mg/g	64.6	92.8	72.1	74.3	11.0	0.09
Total lipid, %	6.46	9.28	7.21	7.43	1.10	0.09
14:0, %	3.45	3.50	3.63	3.87	0.220	0.09
14:1, %	1.21	1.25	1.23	1.08	0.149	0.56
16:0, %	25.91	27.30	27.45	26.84	0.541	0.06
16:1, %	5.00	4.37	4.88	5.34	0.407	0.26
18:0, %	11.32	11.35	10.99	10.72	0.366	0.37
18:1 trans, %	2.85	3.32	3.45	3.66	0.588	0.15
18:1 cis 9, %	39.92	39.95	38.21	38.31	1.188	0.17
18:1 cis others, %	2.66	2.56	2.36	2.66	0.250	0.46
18:2, %	3.79	3.28	3.55	3.51	0.155	0.06
18:3, %	0.14	0.09	0.11	0.12	0.030	0.23
SFA, %	40.69	42.08	42.07	41.38	0.732	0.28
MUFA, %	51.64	51.49	50.13	51.07	0.825	0.45
PUFA, %	3.93 ^a	3.38 ^b	3.66 ^{ab}	3.63 ^{ab}	0.156	0.04
MUFA:SFA	1.279	1.226	1.194	1.240	0.042	0.37
PUFA:SFA	0.097 ^a	0.080 ^b	0.087 ^{ab}	0.088 ^{ab}	0.004	0.02
Desaturase index (14) [†]	25.63	25.77	24.92	21.62	1.787	0.09
Desaturase index (16) [†]	16.12	13.80	15.00	16.50	1.004	0.12
Desaturase index (18) [†]	77.85	77.92	77.62	78.14	0.796	0.95

^{a-c}Sire breed lsmean estimates within a row with a different superscript differ ($P \leq 0.05$).

*The reported standard error of the mean is the greatest between the sire breeds.

[†]Index of delta desaturase enzyme activity on the conversion of 14:0 to 14:1, 16:0 to 16:1, and 18:0 to 18:1 cis 9 [e.g., = $100 \times (18:1 \text{ cis } 9 / (18:0 + 18:1 \text{ cis } 9))$].

muscle and various adipose depots of purebred Jersey steers. The fatty acid composition of muscle from purebred Jersey steers reported by Jiang et al. (2013) was very similar to the results found in the present study. Previous research comparing different breeds of cattle report Jersey cattle as having unique and desirable fat characteristics, such as a greater percentage of MUFA, which results in softer fat. Siebert et al. (1996) reported greater percentages of intramuscular fat for early maturing cattle breeds, including Jerseys, compared with later maturing cattle breeds (Simmental, Charolais). Siebert et al. (1996) reported along with greater intramuscular fat content, there was an increase in the percentage of neutral lipids, particularly MUFA as palmitoleic (16:1) and oleic (18:1) acids and a decrease in the percentage of PUFA, specifically linoleic (18:2) acid. Pitchford et al. (2002) reported Jersey sired cattle to have a similar index of desaturation to Wagyu sired cattle, but a greater index when compared with cattle from other sire breeds (Angus, Hereford, South Devon, Limousin, and Belgian Blue). As a result of a greater index of desaturation, Jersey and Wagyu sired cattle had a greater percentage of MUFA, which resulted in a lesser

fat melting point compared with cattle from other sire breeds (Pitchford et al., 2002). The findings of Pitchford et al. (2002) are supported by the results of Siebert et al. (2003) when they compared Jersey and Limousin sired cattle. Jersey sired cattle had a greater percentage of intramuscular fat, desaturase enzyme activity, MUFA, and a lesser fat slip point, indicating softer fat compared with Limousin sired cattle (Siebert et al., 2003). However, as mentioned previously by Siebert et al. (1996) and herein, when intramuscular fat content is adjusted to a similar level, the fatty acid composition of different breeds of cattle is quite similar if cattle are fed and managed the same.

Value-Added Potential

Niche markets for beef products commonly establish well defined labeling criteria that have a real or perceived positive effect on characteristics related to eating quality, sustainability, management or rearing practices, human health benefits, and other attributes desired by the consumer. Niche markets can provide an opportunity to add value to beef products that meet these previously mentioned

intrinsic and extrinsic characteristics desired by the consumer. A goal of the present study was to evaluate the potential use of labeling claims for value-added opportunities created from implementing a crossbreeding program between Jersey cows and a terminal beef sire. The present study demonstrates the feasibility, and inherent opportunities and challenges encountered when raising purebred and crossbred Jersey steers to market ready weights without the use of exogenous growth promoting technologies (e.g., hormone implants and β -agonists), while meeting a consumer desire for beef raised without the use of exogenous growth promoting technologies. Lusk and Fox (2002) reported that 85% of consumers in the United States would prefer mandatory labeling of beef administered exogenous hormones; however, only 68% of consumers were willing to pay a premium for beef with this type of labeling. Their results demonstrated the average consumer would be willing to pay a 17% greater price for beef labeled with exogenous hormone use status, and consumers with a greater concern about the safety of exogenous hormone use were willing to pay greater than a 17% price increase (Lusk and Fox, 2002). Feeding dairy cattle for beef production, including Jersey influenced cattle, would provide a greater opportunity to account for the traceability of beef products. Dickinson and Bailey (2002) reported U.S. consumers would be willing to pay an additional \$0.23 for a \$3 roast beef sandwich if the beef was traceable. Consumers were willing to pay an additional \$0.50, \$0.63, or \$1.06 for added assurances for animal welfare, food safety, or all three extrinsic factors, respectively (Dickinson and Bailey, 2002).

Purebred Jersey steers in the present study demonstrated the ability to deposit marbling to achieve a USDA QG of Average Choice across the population of cattle studied. Implementing a crossbreeding program between Jersey cows and a terminal beef sire selected for marbling ability, as in the present study, produced crossbred Jersey steers with average USDA QG of Low Prime/High Choice. Marbling or intramuscular fat is a factor contributing to beef eating satisfaction, and as a result, is used to determine the USDA QG of beef. A consumer laboratory sensory panel comparing high marbling (upper 2/3 Choice, 8.81% fat) and low marbling (Select, 6.05% fat) strip steaks, with a similar WBSF value, rated greater flavor, juiciness, and overall acceptability scores for high marbled strip steaks compared with low marbled strip steaks (Killinger et al., 2004). Of the consumers (33%) with consistent acceptability ratings, 71% found high marbling

beef to be more acceptable (Killinger et al., 2004). As a result, consumers were willing to pay more for a steak with the amount of marbling they preferred, \$2.49 and \$3.24/kg for high marbled steaks by consumers from Chicago and San Francisco, respectively (Killinger et al., 2004). Platter et al. (2005) also reported U.S. consumers would be more willing to purchase and willing to pay an additional \$0.89 and \$2.47/kg for Premium Choice (upper 2/3 Choice) and Prime strip steaks, respectively, when compared with Select strip steaks.

Jersey influenced steers from the present study produced ribeye steaks that would qualify for the USDA AMS labeling claim "very tender" (<3.9 kg WBSF) after 7 d of post mortem aging. This finding provides strong evidence for Jersey influenced steers to meet niche markets with tenderness-based claims. Miller et al. (2001) reported that U.S. consumers are able to differentiate beef tenderness, with WBSF values of <3.0, <3.4, and <4.9 resulting in tenderness acceptability 100%, 99%, and 37% to 59% of the time, respectively. U.S. consumers (78%) would also be willing to pay a premium price for a guaranteed tender steak (Miller et al., 2001). In disagreement with reports from Miller et al. (2001), Lusk et al. (2001) reported 69% of consumers preferred tender steak, but only 36% were willing to pay a premium to receive a guaranteed tender steak. However, when tenderness status (tender, <15 kg SSF vs. tough, >35 kg SSF) was revealed to the consumer, of the 84% of consumers preferring tender steaks, only 51% were willing to pay a premium for a guaranteed tender steak (Lusk et al., 2001). The average willingness to pay for a guaranteed tender steak was \$2.71 and \$4.06/kg if the tenderness status was unknown or known by the consumer, respectively. Data reported by Miller et al. (2001) demonstrate a \$0.37/kg increase in price for every 1.0 kg decrease in WBSF. In agreement, Platter et al. (2005) reported an even greater increase (\$1.02/kg) in the willingness of U.S. consumers to pay a premium for every 1.0 kg decrease in WBSF. Overall, an apparently large percentage of U.S. consumers would be willing to pay a premium for beef labeled as "very tender," of which the Jersey influenced steers from the present study would certainly qualify.

Many consumers have negative connotations about fat affecting their health and make their meat purchasing decisions based on leanness (Grunert et al., 2004). As a result, some consumers are sacrificing some of the desired eating quality characteristics (flavor, juiciness, tenderness) of a highly marbled steak by choosing to purchase steaks from

the retailer with a lesser degree of marbling. As mentioned in the discussion previously, as the level of marbling or intramuscular fat deposition increases, the proportion of MUFA, as oleic acid, increases as well. Research regarding the consumption of highly marbled beef has reported health benefits, such as increasing the plasma high density lipoprotein-cholesterol (HDL), while decreasing the plasma low density lipoprotein-cholesterol (LDL) in human subjects resulting in improved cardiovascular health (Adams et al., 2010, Gilmore et al., 2011, 2013; Crouse et al., 2016). While nutritional requirements are different for each individual person, the consumption of highly marbled Jersey influenced beef may have potential health benefits. Although, future research is warranted to make such labeling claims.

Implications

Raising Jersey dairy steers for beef production can be economically challenging for producers and cattle feeders due a lesser ADG and feed efficiency compared with commercial beef cattle. In addition to inferior feedlot performance, Jersey steers are finely muscled and have extremely low retail yields compared with commercial beef cattle. A crossbreeding program between Jersey dairy cows with a terminal beef sire, as reported in the present study, resulted in improved feedlot performance and retail yield for crossbred Jersey steers compared with purebred Jersey steers, although still inferior to commercial beef cattle in the U.S. beef industry. To decrease the gap between Jersey influenced cattle and commercial beef cattle, terminal sire selection must consider growth rate and muscling ability. While not an aim of the present study, the use of exogenous growth promoting technologies (e.g., hormone implants and β -agonists) may be used to improve the growth rate and retail yield of Jersey influenced cattle; however, their use may negatively affect marbling deposition and tenderness. Therefore, the use of grow promoting technologies may limit value-added opportunities in niche markets (e.g., nonhormone treated cattle) driven by meeting consumer desires. Additional research is needed to quantify the effects of feedlot performance, carcass yield, and carcass quality for Jersey influenced cattle raised with the use of growth promoting technologies. Overall, crossbred Jersey steers raised in the present study have demonstrated added value to participants in the beef and dairy industries with improved feedlot performance and carcass composition compared with purebred Jersey steers.

ACKNOWLEDGMENTS

Salary support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. We are grateful to the American Jersey Association (Reynoldsburg, OH) and OARDC SEEDS grant for providing funding for this research. We also would like to acknowledge the staff at the Ohio Agricultural Research and Development Center Feedlot (Wooster, OH) and the staff of the Ohio State University Meat Sciences Laboratory (Columbus, OH) for their assistance with conducting this research.

Conflict of interest statement. None declared.

LITERATURE CITED

- Adams, T. H., R. L. Walzem, D. R. Smith, S. Tseng, and S. B. Smith. 2010. Hamburger high in total, saturated and trans-fatty acids decreases HDL cholesterol and LDL particle diameter, and increases TAG, in mildly hypercholesterolaemic men. *Br. J. Nutr.* 103:91–98. doi:10.1017/S0007114509991516
- AMSA. 2015. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. Champaign (IL): American Meat Science Association.
- AOAC. 1984. Official methods of analysis. 14th ed. Washington (DC): Association of Official Analytical Chemists.
- Arnett, E. J., F. L. Fluharty, S. C. Loerch, H. N. Zerby, R. A. Zinn, and P. S. Kuber. 2012. Effects of forage level in feedlot finishing diets on carcass characteristics and palatability of Jersey beef. *J. Anim. Sci.* 90:960–972. doi:10.2527/jas.2011-4027
- ASTM. 2011. Standard specification for tenderness marketing claims associated with meat cuts derived from beef. West Conshohocken (PA): ASTM International.
- Boykin, C. A., L. C. Eastwood, M. K. Harris, D. S. Hale, C. R. Kerth, D. B. Griffin, A. N. Arnold, J. D. Hasty, K. E. Belk, D. R. Woerner, et al. 2017. National Beef Quality Audit–2016: in-plant survey of carcass characteristics related to quality, quantity, and value of fed steers and heifers. *J. Anim. Sci.* 95:2993–3002. doi:10.2527/jas.2017.1543
- Bumsted, J., L. M. Hoffman, R. S. Metzger, A. D. Blair, S. M. Scramlin, and K. R. Underwood. 2014. Tenderness and palatability traits of beef from Limousin \times Jersey cross bred steers and Certified Angus Beef. *Meat Sci.* 96:473. Abstract. doi:10.1016/j.meatsci.2013.07.110
- Charles, D. D., and E. R. Johnson. 1976. Breed differences in amount and distribution of bovine carcass dissectible fat. *J. Anim. Sci.* 42:332–341. doi:10.2527/jas1976.422332x
- Cole, J. W., C. B. Ramsey, C. S. Hobbs, and R. S. Temple. 1964. Effects of type and breed of British, zebu, and dairy cattle on production, carcass composition, and palatability. *J. Dairy Sci.* 47:1138–1144. doi:10.3168/jds.S0022-0302(64)88863-9
- Crouse, S. F., J. S. Green, T. H. Meade, D. R. Smith, and S. B. Smith. 2016. Exercise raises high-density lipoprotein cholesterol in men after consumption of ground beef with a high but not low monounsaturated fatty acid-saturated

- fatty acid ratio. *Nut. Res.* 36:974–981. doi:10.1016/j.nutres.2016.06.013
- Dickinson, D. L., and D. Bailey. 2002. Meat traceability: are U.S. consumers willing to pay for it? *J. Agri. Res. Econ.* 27:348–364.
- Doreau, M., D. Rearte, J. Portelli, and J. L. Peyraud. 2007. Fatty acid ruminal metabolism and digestibility in cows fed perennial ryegrass. *Europ. J. Lipid Sci. Tech.* 109:790–798. doi:10.1002/ejlt.200700003
- FASS. 2010. Guide for the care and use of agricultural animals in agricultural research and teaching. Consortium for developing a guide for the care and use of agricultural animals in agricultural research and teaching. Champaign (IL): Federation of Animal Science Societies.
- Folch, J., M. Lees, and G. H. Sloane Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* 226:497–509.
- Gilmore, L. A., S. F. Crouse, A. Carbuhn, J. Klooster, J. A. E. Calles, T. Meade, and S. B. Smith. 2013. Exercise attenuates the increase in plasma monounsaturated fatty acids and high density lipoprotein cholesterol but not high-density lipoprotein 2b cholesterol caused by high-oleic ground beef in women. *Nut. Res.* 33:1003–1011. doi:10.1016/j.nutres.2013.09.003
- Gilmore, L. A., R. L. Walzem, S. F. Crouse, D. R. Smith, T. H. Adams, V. Vaidyanathan, X. Cao, and S. B. Smith. 2011. Consumption of high-oleic acid ground beef increases HDL cholesterol concentration but both high- and low-oleic acid ground beef decrease HDL particle diameter in normocholesterolemic men. *J. Nut.* 141:1188–1194. doi:10.3945/jn.110.136085
- Greenwood, P. L., L. M. Cafe, H. Hearnshaw, D. W. Hennessy, J. M. Thompson, and S. G. Morris. 2006. Long-term consequences of birth weight and growth to weaning on carcass, yield and beef quality characteristics of Piedmontese and Wagyu-sired cattle. *Aust. J. Exp. Agri.* 46:257–269. doi:10.1071/EA05240
- Grunert, K. G., L. Bredahl, and K. Brunsø. 2004. Consumer perception of meat quality and implications for product development in the meat sector—a review. *Meat Sci.* 66:259–272. doi:10.1016/S0309-1740(03)00130-X
- Jiang, T., C. J. Mueller, J. R. Busboom, M. L. Nelson, J. O’Fallon, and G. Tschida. 2013. Fatty acid composition of adipose tissue and muscle from Jersey steers was affected by finishing diet and tissue location. *Meat Sci.* 93:153–161. doi:10.1016/j.meatsci.2012.08.013
- Kempster, A. J., A. Cuthbertson, and G. Harrington. 1976. Fat distribution in steer carcasses of different breeds and crosses. I. Distribution between depots. *Anim. Sci.* 23:25–34. doi:10.1017/S0003356100031044
- Killinger, K. M., C. R. Calkins, W. J. Umberger, D. M. Feuz, and K. M. Eskridge. 2004. Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing in marbling level. *J. Anim. Sci.* 82:3294–3301. doi:10.2527/2004.82113294x
- Koch, R. M., and M. E. Dikeman. 1977. Characterization of biological types of cattle. V. Carcass wholesale cut composition. *J. Anim. Sci.* 45:30–42. doi:10.2527/jas1977.45130x
- Koch, R. M., M. E. Dikeman, D. M. Allen, M. May, J. D. Crouse, and D. R. Campion. 1976. Characterization of biological types of cattle III. Carcass composition, quality and palatability. *J. Anim. Sci.* 43:48–62. doi:10.2527/jas1976.43148x
- Kruk, Z. A., A. E. O. Malau-Aduli, W. S. Pitchford, and C. D. K. Bottema. 1998. Genetics of fat colour in cattle. In: *Proceedings 6th World Congress on Genetics Applied to Livestock Production*. vol. 23. Armidale (Australia): The University of New England. p. 121–124.
- Lehmkuhler, J. W., and M. H. Ramos. 2008. Comparison of dairy beef genetics and dietary roughage levels. *J. Dairy Sci.* 91:2523–531. doi:10.3168/jds.2007-0526
- Lusk, J. L., and J. A. Fox. 2002. Consumer demand for mandatory labeling of beef from cattle administered growth hormones or fed genetically modified corn. *J. Agri. Appl. Econ.* 34:27–38. doi:10.1017/S1074070800002121
- Lusk, J. L., J. A. Fox, T. C. Schroeder, J. Mintert, and M. Koochmarai. 2001. In-store valuation of steak tenderness. *Am. J. Agri. Econ.* 83:539–550. doi:10.1111/0002-9092.00176
- Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. *J. Anim. Sci.* 79:3062–3068. doi:10.2527/2001.79123062x
- Motoyama, M., K. Sasaki, and A. Watanabe. 2016. Wagyu and the factors contributing to its beef quality: a Japanese industry overview. *Meat Sci.* 120:10–18. doi:10.1016/j.meatsci.2016.04.026
- Mukhoty, H., and R. T. Berg. 1971. Influence of breed and sex on the allometric growth patterns of major bovine tissues. *Anim. Sci.* 13:219–227. doi:10.1017/S0003356100029652
- NAAB. 2015. Annual reports of semen sales and custom freezing. Columbia (MO): National Association of Animal Breeders. Available from <https://www.naab-css.org/semen-sales>
- NRC. 2000. Nutrient requirements of beef cattle. 7th rev. ed. Washington (DC): National Academy Press.
- Page, J. K., D. M. Wulf, and T. R. Schwotzer. 2001. A survey of beef muscle color and pH. *J. Anim. Sci.* 79:678–687. doi:10.2527/2001.793678x
- Pitchford, W. S., M. P. B. Deland, B. D. Siebert, A. E. O. Malau-Aduli, and C. D. K. Bottema. 2002. Genetic variation in fatness and fatty acid composition of crossbred cattle. *J. Anim. Sci.* 80:2825–2832. doi:10.2527/2002.80112825x
- Platter, W. J., J. D. Tatum, K. E. Belk, S. R. Koontz, P. L. Chapman, and G. C. Smith. 2005. Effects of marbling and shear force on consumers’ willingness to pay for beef strip loin steaks. *J. Anim. Sci.* 83:890–899. doi:10.2527/2005.834890x
- Radunz, A. E., S. C. Loerch, G. D. Lowe, F. L. Fluharty, and H. N. Zerby. 2009. Effect of Wagyu- versus Angus-sired calves on feedlot performance, carcass characteristics, and tenderness. *J. Anim., Sci.* 87:2971–976. doi:10.2527/jas.2009-1914
- Ramsey, C. B., J. W. Cole, B. H. Meyer, and R. S. Temple. 1963. Effects of type and breed of British, zebu and dairy cattle on production, palatability and composition. II. Palatability differences and cooking losses as determined by laboratory and family panels. *J. Anim. Sci.* 22:1001–1008. doi:10.2527/jas1963.2241001x
- Retallick, K. M., D. B. Faulkner, S. L. Rodriguez-Zas, J. D. Nkrumah, and D. W. Shike. 2013. The effect of breed and individual Heterosis on the feed efficiency, performance, and carcass characteristics of feedlot steers. *J. Anim. Sci.* 91:5161–166. doi:10.2527/jas.2012-6155
- Sasaki, Y., T. Miyake, C. Gaillard, T. Oguni, M. Matsumoto, M. Ito, T. Kurahara, Y. Sasae, K. Fujinaka, S. Ohtagaki,

- and T. Dougo. 2006. Comparison of genetic gains per year for carcass traits among breed programs in the Japanese Brown and the Japanese Black cattle. *J. Anim. Sci.* 84:317–323. doi:10.2527/2006.842317x
- Siebert, B. D., M. P. Deland, and W. S. Pitchford. 1996. Breed differences in fatty acid composition of subcutaneous and intramuscular lipid of early and late maturing, grain-finished cattle. *Aust. J. Agric. Res.* 47:943–952.
- Siebert, B. D., W. S. Pitchford, Z. A. Kruk, H. Kuchel, M. P. Deland, and C. D. Bottema. 2003. Differences in Δ^9 desaturase activity between Jersey- and Limousin-sired cattle. *Lipids.* 38:539–543. doi:10.1007/s11745-003-1339-7
- Smith, G. M., D. B. Laster, L. V. Cundiff, and K. E. Gregory. 1976. Characterization of biological types of cattle II. Postweaning growth and feed efficiency of steers. *J. Anim. Sci.* 43:37–47. doi:10.2527/jas1976.43137x
- Tian, R., W. S. Pitchford, C. A. Morris, N. G. Cullen, and C. D. K. Bottema. 2010. Genetic variation in the β , β -carotene-9', 10'-dioxygenase gene and association with fat colour in bovine adipose tissue and milk. *Anim. Gen.* 41:253–259. doi:10.1111/j.1365-2052.2009.01990.x
- USDA. 2014. Institutional meat purchase specifications fresh beef series 100. Washington, (DC): Agricultural Marketing Service, USDA.
- Wheeler, T. L., L. V. Cundiff, S. D. Shackelford, and M. Koochmaraie. 2004. Characterization of biological types of cattle (Cycle VI): carcass, yield, and longissimus palatability traits. *J. Anim. Sci.* 82:1177–1189. doi:10.2527/2004.8241177x
- Wulf, D. M., and J. W. Wise. 1999. Measuring muscle color on beef carcasses using the L* a* b* color space. *J. Anim. Sci.* 77:2418–2427.
- Young, L. D., L. V. Cundiff, J. D. Crouse, G. M. Smith, and K. E. Gregory. 1978. Characterization of biological types of cattle. VIII. Postweaning growth and carcass traits of three-way cross steers. *J. Anim. Sci.* 46:1178–1191. doi:10.2527/jas1978.4651178x