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Post-weaning management of modern dairy cattle genetics for beef production: a review

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Abstract

The contribution of dairy steers to the U.S. fed beef supply has increased from 6.9% to 16.3% over the last two decades; in part, due to declining beef cow numbers and the increased use of sexed dairy semen to produce genetically superior replacement heifers from the best dairy cows. Raising dairy cattle for beef production offers unique opportunities and challenges when compared with feeding cattle from beef breeds. Dairy steers offer predictable and uniform finishing cattle performance (ADG, DMI, G:F) as a group and more desirable quality grades on average compared with their beef steer counterparts. However, dairy steers have lesser dressing percentages and yield 2%–12% less red meat compared with beef steers due to a greater ratio of bone to muscle, internal fat, organ size, and gastrointestinal tract weight. In addition, carcasses from dairy steers can present problems in the beef packing industry, with Holstein carcasses being longer and Jersey carcasses being lighter weight than carcasses from beef breeds. Beef × dairy crossbreeding strategies are being implemented on some dairy farms to increase the income generated from dairy bull calves, while beef × dairy crossbreeding strategies can also improve the G:F and red meat yield of beef produced from the U.S. dairy herd. This alternative model of beef production from the dairy herd is not without its challenges and has resulted in variable results thus far. Successful adoption of beef × dairy crossbreeding in the cattle industry will depend on the proper selection of beef sires that excel in calving ease, growth, muscling, and marbling traits to complement the dairy genetics involved in beef production.

Lay Summary

The number of dairy steers contributing to the U.S. fed beef supply has increased from 6.9% to 16.3% over the last two decades. Raising dairy cattle breeds for beef production offers unique opportunities and challenges when compared with feeding beef cattle breeds. Dairy steers offer predictable and uniform finishing cattle performance (ADG, DMI, G:F) as a group and more desirable quality grades on average compared with their beef steer counterparts. Dairy steers yield less red meat compared with beef steers due to a greater ratio of bone to muscle, internal fat, organ size, and gastrointestinal tract weight. The use of growth-promoting technologies such as hormonal implants and β-adrenergic agonists can help improve finishing cattle performance and increase the red meat yield of dairy-influenced steers. In addition, beef × dairy crossbreeding strategies are being implemented on some dairy farms to increase the income generated from bull calves, while beef × dairy crossbreeding strategies can also improve the gain:feed and red meat yield of beef produced from the U.S. dairy herd. Successful adoption of beef × dairy crossbreeding in the cattle industry will depend on the proper selection of beef sires to complement the challenges and opportunities experienced with dairy genetics for beef production. Early calfhood management practices should be investigated further to determine their impacts on the subsequent finishing performance and carcass characteristics of calves produced by dairy farms for beef production.

Key words: beef, dairy, Holstein, Jersey

Abbreviations: ADG, average daily gain; BF, backfat thickness; BW, body weight; DMI, dry matter intake; DP, dressing percent; E_2, estradiol; EPD, expected progeny difference; G:F, gain:feed; HCW, hot carcass weight; KPH, kidney, pelvic, and heart fat; LMA, longissimus muscle area; NDF, neutral detergent fiber NEg, net energy for gain; QG, quality grade; RAC, ractopamine hydrochloride; SSF, slice shear force; TBA, trenbolone acetate; WBSF, Warner Bratzler-shear force; ZIL, zilpaterol hydrochloride

Introduction

Male calves produced on dairy farms are often seen as a byproduct of the dairy industry. However, the contribution of these dairy byproduct calves that are raised for beef production contributes substantially to the U.S. beef supply. The most recent National Beef Quality Audit (Boykin et al., 2017) estimated that 16.3% of the fed cattle supply consisted of dairy-type cattle, a 9–10 percentage unit increase from 7.3% and 6.9% in the early 1990s and early 2000s (Lorenzen et al., 1993, McKenna et al., 2002). As a result of decreasing beef cow numbers and decreasing calf slaughter for veal production the proportion of calves raised for beef each year has increasingly been dairy influenced.

In 2021, 9.4 million dairy cows represented 24% of the cows that calved (approximately 9.38 million calves) in the U.S. (USDA, 2022; Figure 1). From 2007 to 2015, the use of female sexed semen on Holstein heifers increased from 9% to 31% (Hutchison and Bickhart, 2016). Likewise, from 2005 to 2021, the number of dairy replacement heifers increased by 317,000 head (USDA, 2005; USDA, 2022). Currently, the greater supply of dairy replacement heifers in the U.S. has reduced their market value, thus allowing dairy producers

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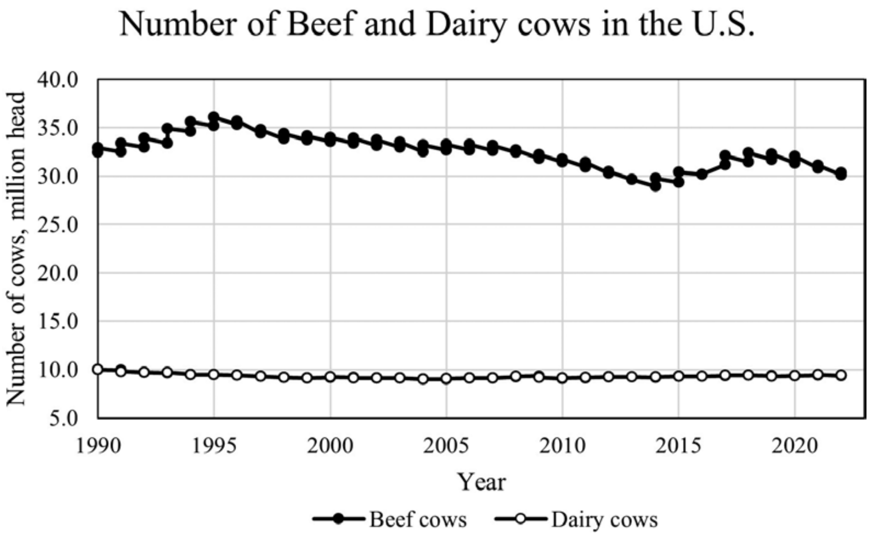

Figure 1. Number of beef (●) and dairy cows (○) in the U.S. reported by United States Department of Agriculture National Agricultural Statistics Service on the first day of January and July of each year from 1990 to 2022.

the ability to purchase their replacement heifers cheaper than they can raise them (Overton and Dhuyvetter, 2020). An oversupply of dairy replacement heifers can become costly if the dairy operation is not able to manage a greater number of cows. However, the use of sexed semen has also created an opportunity for dairy producers to implement a beef × dairy crossbreeding strategy that allows for the production of beef × dairy calves that can be raised or sold into beef production for greater value compared with straightbred dairy calves (Cabrera, 2022; McCabe et al., 2022).

This review will build upon past reviews focused on dairy beef production (Cartwright, 1983; Managing and Marketing Quality Holstein Steers Proceedings, 2005; Duff and McMurphy, 2007; Peters, 2014; Schaefer et al., 2017) and aims to highlight some of the current and key differences between dairy and beef steers. Recently acquired finishing cattle performance, and subsequent carcass data are reviewed for the most popular dairy breeds finished in beef production systems, Holstein and Jersey (Guinan et al., 2019). Discussion is provided on some of the current challenges with raising straightbred dairy steers for beef. The use of growth-promoting technologies with dairy steers is discussed as a solution to mitigate deficiencies between dairy and beef steers. This manuscript also reviews the current status of the dairy progeny being fed in the beef industry and the increasing prevalence of beef semen being used in dairy operations. Lastly, this review will highlight areas in the industry requiring future research to improve the efficiency of beef production from dairy systems in the U.S.

Finishing Cattle Performance and Carcass Characteristics of Dairy Beef Cattle

Genetics of both beef and dairy cattle breeds have greatly changed over the last century. This review will focus on studies from the last two decades that compare finishing cattle performance and subsequent carcass characteristics of dairy steers with beef steers (summarized in Tables 1 and 2). Comparisons between dairy-type and beef-type steers are difficult to make because each breed's unique phenotype has been selected to excel in dairy or beef production systems, respectively. Differences in fat deposition throughout the carcass of beef and dairy-type steers, as well as differences in mature frame size and weight, ultimately result in different slaughter endpoints. In addition, dairy steers are typically raised in one of two U.S. production systems, as calf-feds, where they are fed grain-based diets near weaning, or as yearlings, where they may be backgrounded on forage-based diets or allowed to graze pasture prior to feedlot entry. Although the terminology used is similar across cattle production systems, the actual management practices differ markedly when referencing calf-fed vs. yearling management strategies for dairy-type and beef-type cattle.

Calf-fed dairy steers usually leave the dairy operation before a week of age and are raised at a calf ranch or calf-raising operation before entering the feedlot. These dairy steer calves will be introduced to an energy-dense calf starter ($NE_g \geq 1.3$ Mcal/kg) and weaned from a milk replacer around 8 weeks (56 d) of age. Calf-fed dairy steers are then sent to feedlots at approximately 125–182 kg or 12–16 weeks of age. Yearling-fed dairy steers undergo a period of backgrounding on a less energy dense diet ($NE_g < 1.3$ Mcal/kg) before entering the feedlot. During this period of backgrounding, dairy steers may be fed a diet that may include feed refusals from a dairy operation, a forage-based diet, or even pasture in a stocker grazing system. Conversely, what the industry calls "calf-fed" beef cattle, from beef breeds, typically enter the feedlot shortly after weaning, around 7 months of age, whereas yearling cattle from beef breeds are approximately 12–16 months of age before entering the feedlot.

Perhaps the greater disadvantage between dairy-type cattle and cattle from beef breeds lies in the conversion of feed to meat, regardless of the production system. The value of dairy steers is not determined by the weight at which calves enter the feedlot, but by how quickly and efficiently they grow and how they deposit fat in their carcass. As a result, comparisons between dairy and beef breeds for growth performance and carcass characteristics will be discussed because of their economic importance.

Table 1. Finishing cattle performance of dairy-type steers in the United States from the past 6 years.

Reference	Breed [1]	Finishing Diet [2]	Treatment	DOF [3]	ADG [3]	DMI [3]	G:F [3]	IW [3]	FW [3]
Torrentera et al. (2017)	HO	SFC:hay (11.5)	Non-implanted	224	1.28	7.75	0.165	264	549
		NE_g = 1.53–1.70	Implanted at 267 kg		1.51	8.41	0.180	267	605
			Implanted at 291 kg		1.51	8.19	0.184	264	601
			Implanted at 321 kg		1.46	8.02	0.182	263	589
Carvalho et al. (2020)	HO	CC:CS (17.0)	Non-implanted	186	1.44	9.47	0.154	274	542
		NE_g = 1.41	Implanted		1.73	11.02	0.158	276	598
Quinn et al. (2020)	HO	SFC:corn stalk/hay (6.2)	CS1H		1.30		0.160	146	632
		NE_g = 1.55	DS1CH		1.31		0.164	146	635
			DXSCH		1.28		0.158	147	625
Lockard et al. (2020)	HO	SFC:hay (12.9)	No Rac	157 + 28 to 42	1.03	9.50	0.106	599	635
		NE_g = 1.43	300 mg Rac		1.23	9.52	0.128	598	641
			400 mg Rac		1.25	9.58	0.129	596	640
			28-d supplementation	28	1.21	9.72	0.123	605	639
			35-d supplementation	35	1.17	9.56	0.121	598	639
			42-d supplementation	42	1.14	9.36	0.121	591	639
Hergenreder et al. (2021)	HO	SFC:wheat straw/hay (12.3)	No Rac	310 + 28	1.38	10.07	0.135	547	587
		NE_g = 1.53	400 mg Rac		1.61	9.57	0.167	547	594
Walter et al. (2016)	HO	SFC:wheat hay (8.5)	No Zil	225 + 20	1.59	8.22	0.194	469	513
May et al. (2016)		NE_g = 1.49	8.3 mg Zil		1.54	7.85	0.198	462	505
				253 + 20	1.04	9.03	0.114	503	532
					0.96	8.11	0.118	492	519
				281 + 20	2.28	10.81	0.212	517	581
					1.56	8.80	0.174	497	541
				309 + 20	1.67	10.73	0.160	560	607
					1.74	9.58	0.178	575	624
				337 + 20	1.91	6.42	0.202	560	613
					2.28	9.46	0.240	593	656
				365 + 20	1.49	11.38	0.132	626	668
					1.98	11.33	0.176	655	711
				393 + 20	1.14	10.97	0.105	701	733
					1.37	9.09	0.144	673	711
				421 + 20	0.6	10.87	0.054	734	751
					0.88	10.10	0.086	754	779
				449 + 20	1.71	9.94	0.172	769	816
					2.36	10.45	0.228	763	829
				477 + 20	1.66	10.31	0.160	787	833
					1.17	9.41	0.106	833	866
				505 + 20	0.81	9.25	0.092	783	806
					1.36	10.41	0.134	823	861
Jaborek et al. (2019a)	JE × JE	WSC:CS or SH (20.0)	JE × JE	346	0.85	6.67	0.123	222	496
	AN × JE	NE_g = 1.47–1.49	AN × JE	304	1.05	7.72	0.133	224	520
	SA × JE		SA × JE	314	1.08	7.35	0.135	198	515
	RW × JE		RW × JE	331	0.97	6.80	0.142	194	502

[1]HO, Holstein, JE = Jersey, AN, Angus, SA SimAngus, RW, Red Wagyu.
[2]SFC, steam-flaked corn, CC, cracked corn, WSC, whole-shelled corn, CS, corn silage, SH, soyhulls, NE_g, net energy for gain. Ratio of grain to forage, with the percentage of forage in the finishing diet shown in parentheses.
[3] DOF, days on feed, d; ADG, average daily gain, kg/d; DMI, average daily dry matter intake, kg/d; G:F, gain:feed, kg gain:kg feed; IW, initial weight, kg; FW, final weight, kg.

Holsteins

Holstein steers, fed a whole-shelled corn/corn silage finishing diet to achieve a low choice USDA QG, determined via ultrasound and confirmed at slaughter, had reduced average daily gains (ADG; 31%), dry matter intakes (DMI; 6%), and gain to feed ratios (G:F; 23%) when compared with Angus and SimAngus steers (Perry et al., 1991). At marbling scores of small, Holstein steer carcasses had a lesser back fat (BF; 54%) thickness and longissimus muscle area (LMA; 8%) compared with Angus and SimAngus steers, with no differences in taste

Table 2. Carcass characteristics of dairy-type steers in the United States from the past 6 years.

Reference	Breed [1]	Finishing Diet [2]	Treatment	DOF [3]	HCW [3]	DP [3]	BFT [3]	LMA [3]	KPH [3]	MS [3]
Torrentera et al. (2017)	HO	SFC:hay (11.5)	Non-implanted	224	342	62.41	1.23	73.7	2.35	547
		NE_g = 1.53–1.70	Implanted at 267 kg		375	62.03	1.09	81.2	2.17	517
			Implanted at 291 kg		376	62.61	1.09	80.6	1.93	581
			Implanted at 321 kg		366	62.15	1.19	80.7	2.10	503
Carvalho et al. (2020)	HO	CC:CS (17.0)	Non-implanted	186	305	58.72	0.61	68.3	2.86	467
		NE_g = 1.41	Implanted		338	58.84	0.55	72.4	2.56	461
Quinn et al. (2020)	HO	SFC:corn stalk/hay (6.2)	CS1H		385					
		NE_g = 1.55	DS1CH		387					
			DXSCH		381					
Lockard et al. (2020)	HO	SFC:hay (12.9)	No Rac	157 + 28 to 42	383	60.2	0.88	78.0		484
		NE_g = 1.43	300 mg Rac		386	60.3	0.86	79.3		471
			400 mg Rac		387	60.4	0.84	80.7		466
			28 day supplementation	28	385	60.3	0.85	80.0		470
			35 day supplementation	35	386	60.3	0.87	78.7		483
			42 day supplementation	42	384	60.3	0.86	79.4		468
Hergenreder et al. (2021)	HO	SFC:wheat straw/hay (12.3)	No Rac	310 + 28	360	61.4	0.66	74.1		430
		NE_g = 1.53	400 mg Rac		368	62.1	0.61	78.2		425
Walter et al. (2016)	HO	SFC:wheat hay (8.5)	No Zil	225 + 20	Average between treatments					
May et al. (2016)		NE_g = 1.49	8.3 mg Zil		296		0.36	64.6	2.7	310
				253 + 20						
					318		0.57	64.1	3.4	327
				281 + 20						
					332		0.52	67.7	3.0	371
				309 + 20						
					333		0.70	76.5	3.4	406
				337 + 20						
					365		0.78	87.4	3.9	401
				365 + 20						
					380		0.89	81.4	4.1	410
				393 + 20						
					415		0.82	82.3	4.1	459
				421 + 20						
					480		1.09	80.6	4.8	420
				449 + 20						
					506		1.32	89.7	4.8	452
				477 + 20						
					531		1.55	88.9	4.4	527
				505 + 20						
					508		1.17	82.8	5.3	489
Jaborek et al. (2019a)	JE × JE	WSC:CS or SH (20.0)	JE × JE	346	304	61.2	0.86	70.3	7.89	586
	AN × JE	NE_g = 1.47–1.49	AN × JE	304	334	64.2	1.37	73.6	5.28	745
	SA × JE		SA × JE	314	332	63.9	1.04	73.6	6.48	651
	RW × JE		RW × JE	331	317	63.2	0.97	76.4	6.43	687

[1] HO, Holstein, JE, Jersey, AN, Angus, SA SimAngus, RW, Red Wagyu.
[2] SFC, steam-flaked corn, CC, cracked corn, WSC, whole-shelled corn, CS, corn silage, SH, soyhulls, NE_g, net energy for gain. Ratio of grain to forage, with the percentage of forage in the finishing diet shown in parentheses.
[3] DOF, days on feed, d; HCW, hot carcass weight, kg; DP, dressing percentage, %; BFT, backfat thickness, cm; LMA, longissimus muscle area, cm^2; KPH, kidney, pelvic, heart fat, %; MS, USDA marbling score (400, small, 500, modest, …).

panel sensory evaluation (Perry et al., 1991). Oftentimes Longissimus muscle shape or confirmation, particularly the Longissimus lumborum, of Holstein steers is credited as a detriment to the consumer's willingness to purchase due to the lesser muscle depth and greater angularity of the lateral end of the steak (Steger, 2014). However, Thonney et al. (1991) reported that people involved with retail meat sales could not differentiate ribeye steaks from Holstein or SimAngus steers and Steger (2014) reported that steak confirmation measurements had weak correlations with the preferences of consumers. These results are in disagreement with older research where Holstein steers had an 11% greater ADG and were 6% to 9% more feed efficient compared with Angus and Hereford steers when fed either a high-moisture ear corn or corn silage diet (Thonney, 1987). However, the comparison of Holstein, Angus, and Hereford steers at a constant weight endpoint could have allowed for greater differences in finishing cattle performance compared with a constant marbling endpoint due to breed differences in mature size and their physiological maturity at 560 kg (Thonney, 1987). It is important to note, as was done earlier, that cattle genetics for both beef and dairy breeds have changed dramatically since the 1980s.

Abney (2004) compared calf-fed and yearling steers of both Holstein and Angus breeds raised to different BF thicknesses (0.76 and 1.02 vs. 1.02 and 1.27 cm, respectively) in two experiments using high-moisture and dry corn/corn silage diets. As calf-feds, Holstein steers gained less weight per day (1.40 vs. 1.87 kg/d), and consumed less DM per day (7.86 vs. 8.54 kg), resulting in a lesser G:F (0.164 vs. 0.189 kg gain/kg DM) and more days on feed (312 vs. 172 d) but with greater final BW (610 vs. 576 kg) when compared with calf-fed Angus steers (Abney, 2004). As yearlings, there were no differences between Holstein and Angus steers for ADG (1.47 and 1.50 kg/d, respectively) and DMI as a percentage of body weight (BW; 2.15% and 2.12%, respectively). However, Holstein steers required more days on feed (170 vs. 116 d) to reach the targeted BF endpoint, had greater final BW (682 vs. 615 kg), had greater daily DMI (12.0 vs. 11.2 kg), and was less feed efficient when compared with Angus steers (0.122 vs 0.133 kg gain/kg DM; Abney, 2004).

Calf-fed Holstein steers had lesser dressing percentages (DP; 56% vs. 59%) and LMA (72.9 vs. 82.6 cm^2) and greater estimated kidney, pelvic, and heart fat (KPH; 4.2% vs. 3.0%) compared with calf-fed Angus steers (Abney, 2004). Similarly, yearling Holstein steers had lesser DP (56% vs. 59%) and LMA (76.8 vs. 83.9 cm^2) and greater estimated KPH (4.0% vs. 3.4%) compared with yearling Angus steers (Abney, 2004). Marbling score was not different between calf-fed steers (small^{90}) but was greater for yearling Holstein steers when compared with yearling Angus steers (modest^{35} vs. small^{70}; Abney, 2004). The lack of difference in marbling scores between calf-fed Angus and Holstein steers may have been the result of calf-fed Angus steers achieving a greater physiological maturity and overall carcass fat percentage, with more DOF than intended, as demonstrated by a BF thickness (1.47 cm) greater than the desired endpoint. Ribeye steaks from the Longissimus thoracis of calf-fed Angus steer carcasses had lesser Warner Bratzler-shear force (WBSF) values (3.21 vs. 3.43 kg) and were rated as more tender (6.0 vs. 5.6) by taste panelists on a 1–8 scale compared with ribeye steaks from calf-fed Holstein steer carcasses (Abney, 2004). However, ribeye steaks from yearling Holstein steer carcasses had reduced WBSF values (3.05 vs. 3.42 kg) resulting in a more tender rating by taste panelists than steaks from yearling Angus steer carcasses (5.7 vs. 5.4). Regardless, steaks from both Holstein and Angus steers from this study would qualify for the USDA "very tender" certification with WBSF values less than 3.9 kg (ASTM, 2011).

A major concern with Holstein steers raised for beef is the cutability or how much meat is obtained from the carcass. The cutability of fed Holstein steer carcasses is less than that of beef-type steer carcasses. Beef-type steer carcasses have approximately 13.1% fat, 16.3% bone, and 70.4% red meat compared with 10.5% fat, 21.2% bone, and 68.2% red meat for Holstein steer carcasses (Lawrence et al., 2010). The lack of muscling for Holstein steer carcasses is evident in the differences in meat-to-bone ratio between beef-type steer carcasses and calf-fed Holstein steer carcasses (4.32:1 vs. 3.22:1, respectively; Lawrence et al., 2010). May et al. (2017) reported a decrease in red meat (−0.022 percentage units/d) and bone (−0.012 percentage units/d) yield, but an increase in carcass fat (0.034 percentage units/d) yield when calf-fed Holstein steers were fed from 254 to 534 days on feed. Currently, the USDA yield grade equation does not accurately predict the cutability of Holstein steers because the USDA yield grade equation lacks a predictor variable to quantify bone yield (Lawrence et al., 2010). As a result of a lesser cutability for Holstein steer carcasses relative to beef steer carcasses, a great deal of research has been conducted on growth-promoting technology use in Holsteins to help improve the cutability of Holstein steers over the last two decades.

Growth-promoting technology use in Holstein steers

The goal of any implant strategy is to improve finishing cattle performance and increase relative muscle mass without negatively affecting marbling deposition and, ultimately, the final USDA QG. The use of hormonal implants in Holstein steers commonly results in greater ADG (5%–20%), DMI (0%–16%), and G:F (2%–13%) compared with non-implanted steers (Perry et al., 1991; Zinn et al., 1999; Scheffler et al., 2003; Torrentera et al., 2017; Carvalho et al., 2020). In addition, the use of hormonal implants can alter LMA (+3% to +10%) and marbling deposition (−−1 to −19%) for Holstein steers (Perry et al., 1991; Zinn et al., 1999; Scheffler et al., 2003; Torrentera et al., 2017; Carvalho et al., 2020). Additional live weight (~50 kg) is required for implanted Holstein steers to achieve similar marbling scores compared with non-implanted Holstein steers (Perry et al., 1991; Torrentera et al., 2017; Carvalho et al., 2020). Determining the most advantageous implant strategy is complex and has many factors to consider such as hormone type, hormone combinations, hormone concentrations, hormone release rate, subsequent implant frequency, implant timing × growth stage, and implant timing × diet interactions, etc. All these factors can individually, or in combination, affect finishing cattle performance and carcass quality. Furthermore, compared with beef breeds, more days on feed required to finish Holstein steers may allow for 3–4 implants compared with 1 or 2 implants in steers from beef breeds, which adds further complexity for determining the appropriate implant strategy.

One way to reduce the number of implants necessary for Holstein steers, relative to steers from beef breeds, may be delaying the initial hormonal implant. Delaying implant administration to Holstein steers upon feedlot arrival has not resulted in differences in finishing cattle performance and marbling deposition (Scheffler et al., 2003; Torrentera et al., 2017; Quinn et al., 2020). Across the three different studies (Scheffler et al., 2003; Torrentera et al., 2017; Quinn et al., 2020), Holstein steer calves differed in feedlot entry weight (212, 264, 146 kg, respectively) and the number of days after feedlot arrival when implanted (112, unknown, 101 d, respectively). However, Scheffler et al. (2003) reported reduced overall ADG by delaying implant administration for 224 d compared with implanting Holstein steers upon feedlot entry or after 112 days on feed (−9.4% and −6.0%, respectively). Feedlot entry can be a very stressful time for calves as they adapt to a new location and diet, all while overcoming immune challenges. Providing cattle additional time between feedlot entry and the administration of the first implant allows cattle to increase their DMI and energy intake to meet the greater energy demands required by the hormonal implant rather than utilize stored energy from fat depots. Delaying hormone implant administration may improve overall G:F because implants would be administered when cattle are the least efficient at converting feed to BW gain later in the feeding period (Scheffler et al., 2003; Quinn et al., 2020). Delaying implant administration from feedlot entry could also help mitigate reduced marbling scores which are commonly reported with the use of trenbolone acetate/estradiol (TBA/E_2) combination implants (Torrentera et al., 2017; Quinn et al., 2020). Hormonal implants down-regulate the genes responsible for intramuscular adipocyte differentiation and lipid filling (Chung et al., 2012; Smith et al., 2017). Therefore, delaying implant administration may reduce the amount of time intramuscular adipocytes are negatively influenced by hormonal implants as indicated by differences in fractional accretion rates of intramuscular fat from non-implanted, implanted upon arrival, and delayed implanted beef steers (Bruns et al., 2005).

Greater implant frequency typically results in a greater number of hormonal implants administered during the feeding period and possible implant payout overlap, which can elevate hormone concentrations and further reduce carcass quality. Zinn et al. (1999) demonstrated that implanting Holstein steers 4 times every 70-d compared with 3 times every 98 d resulted in no significant improvements of ADG, DMI, and G:F, and negatively affected marbling score. In addition, the combined use of TBA and E_2 can increase LMA, but further reduces marbling scores of Holstein steers compared with TBA or E_2 alone (Apple et al., 1991; Zinn et al., 1999).

Long-duration implants are becoming increasingly popular because they reduce the need for additional cattle processing and, thereby, reduce labor costs. To the author's knowledge, there has been only one peer-reviewed study to date comparing these long-duration implants with each other in Holstein steers (Quinn et al., 2020). Future research is needed to investigate whether there are potential differences in behavior, finishing cattle performance, red meat yield, and carcass quality of Holstein and beef steers as a result of implanting with these long-duration implants.

Ractopamine hydrochloride (RAC) and zilpaterol hydrochloride (ZIL) are the only commercially available and approved β-adrenergic agonists for use in finishing cattle currently on the market. Supplementing RAC to Holstein steers before slaughter demonstrated improvements in ADG (14.6%–21.4%) that translated to a greater final BW and hot carcass weight (HCW) when compared with Holsteins not supplemented with RAC (Vogel et al., 2009; Brown et al., 2014; Lockard et al., 2020; Hergenreder et al., 2021). Likewise, G:F was improved (14.2%–23.7%) and LMA is greater (1.7%–5.5%) when compared with Holstein steers not supplemented RAC (Vogel et al., 2009; Brown et al., 2014; Lockard et al., 2020; Hergenreder et al., 2021). The effect of supplementing RAC on the DMI of Holstein steers is conflicting, as some research reports greater DMI (Vogel et al., 2009), and other research reports lesser DMI (Hergenreder et al., 2021). Although, the majority of research available reports no difference in feed intake between Holsteins steers supplemented RAC and those not supplemented RAC (Vogel et al., 2009; Brown et al., 2014, Lockard, et al., 2020). In-feed concentrations, ranging from 200 to 400 mg RAC per steer per day, or varying RAC feeding duration, from 28 to 42 d, have demonstrated inconsistent differences in finishing cattle performance, carcass characteristics, or palatability measurements from Holstein steers. Supplementing RAC to Holstein steers results in slightly reduced marbling scores (−1.2 to −3.7%) compared with Holsteins not supplemented RAC (Vogel et al., 2009; Brown et al., 2014; Lockard et al., 2020; Hergenreder et al., 2021). Meanwhile, slice shear force (SSF) values are greater from steers supplemented RAC compared with steers not supplemented RAC, indicating a less tender steak from Holstein steers supplemented RAC even after 14 or 21 days of post-mortem aging (Martin et al., 2014; Howard et al., 2014b; Lockard et al., 2020). Supplementing RAC to Holstein steers before slaughter increased total red meat yield (0.61–0.86 percentage units), particularly in the round, and decreased fat (0.56–0.63 percentage units) and bone (0.17–0.30 percentage units) yield of those carcasses compared with carcasses from Holstein steers that were not supplemented RAC (Howard et al., 2014a).

Supplementing (ZIL) during the end of the finishing period to Holstein steers also results in greater ADG (6.5%) and G:F (9.7%) when compared with steers not supplemented ZIL (Brown et al., 2014). Carcasses from Holstein steers supplemented ZIL has a greater LMA (8.5%–11.8%) but have a lesser marbling score (1.3%–7.6%) compared with Holstein steers not supplemented ZIL (Beckett et al., 2009; Brown et al., 2014). Similar to RAC, supplementing ZIL to Holstein steers reduced the tenderness of steaks after 16 and 23 d of postmortem aging, with greater WBSF values (3.8 and 3.6 kg, respectively) and SSF values (17.1 and 15.2 kg, respectively) compared with steaks from Holstein steers not supplemented ZIL (3.4 and 3.2 kg; 14.9 and 13.4 kg, respectively; Martin et al., 2014). In agreement, Howard et al. (2014b) reported greater SSF values after 14 and 21 d of postmortem aging (20.5 and 18.2 kg, respectively) from steaks from Holstein steers supplemented ZIL compared with steaks from Holstein steers not supplemented ZIL (16.3 and 15.0 kg, respectively). Supplementing ZIL before slaughter increased total red meat yield (1.96%), particularly in the round, and decreased fat (1.32%) and bone (0.69%) yield of those carcasses compared with carcasses from Holstein steers that were not supplemented ZIL (Howard et al., 2014a). When comparing feeding RAC with ZIL in Holstein steers, ZIL had a greater effect on increasing the total red meat yield of carcasses compared with carcasses from steers fed RAC (Howard et al., 2014a; Howard et al., 2014b). Additional research is also available investigating the effects of days on feed for Holstein steers either supplemented or not supplemented with ZIL on finishing cattle performance, carcass characteristics, and carcass yield (May et al., 2016; Walter et al., 2016; May et al., 2017).

These results demonstrated an improvement in the muscle to bone ratio of carcasses from calf-fed Holstein steers supplemented with a β-adrenergic agonist, perhaps overcoming the previously discussed challenge for beef production from dairy steers. However, the use of β-adrenergic agonists can be detrimental to the beef-eating experience due to reduced tenderness perceived by the consumer.

Jerseys

Jersey cows represented approximately 12.2% of the U.S. dairy herd in 2019 compared with 81.4% of Holstein cows according to Dairy Herd Improvement Association records (Guinan et al., 2019). As a result, there are fewer published studies for feeding Jersey steers. When comparing implanted Holstein and Jersey steers fed a high-moisture corn/corn silage finishing diet, Holstein steers had greater DMI (9.6 vs. 6.2 kg DM/d) and ADG (1.68 vs. 1.17 kg/d) compared with Jersey steers (Lehmkuler and Ramos, 2008). However, Jersey steers had greater G:F (0.19 vs. 0.18) compared with Holstein steers (Lehmkuler and Ramos, 2008). The slower growth rate of Jersey steers resulted in more days on feed (317 vs. 260 d) and lesser HCW (273 vs. 362 kg) and DP (56.1 vs. 58.9%) for Jersey steers when compared with Holstein steers. Carcasses from Jersey steers had lesser LMA (73.9 vs. 79.8 cm^2) and BF thicknesses (0.41 vs. 0.69 cm), but no difference in marbling scores (modest) compared with Holstein carcasses. Jersey carcasses were also reported to have more visceral fat compared with Holstein carcasses (Lehmkuler and Ramos, 2008). On a percentage of carcass weight, Jersey steer carcasses have less red meat yield and greater fat yield relative to Holstein and beef steer carcasses, with no difference in bone yield compared with Holstein steer carcasses, but greater bone yield when compared with beef steer carcasses (Lawrence et al., 2010; Wesley et al., 2019; Jaborek et al., 2019a).

Interestingly, Lehmkuler and Ramos (2008) reported that the finishing performance of Jersey steers was not different when either fed a finishing diet with a greater energy density (NE_g = 1.44 Mcal/kg) or a three-phase diet with increasing energy density (NE_g = 1.23, 1.33, 1.44 Mcal/kg), whereas Holstein steers performed more favorably in the feedlot when fed a finishing diet with a greater energy density compared with the less energy-dense phase-fed diet. In addition, carcasses from Jersey steers fed the less energy-dense phase-fed diet had no differences for HCW, DP, and LMA, but lesser marbling scores and BF thicknesses compared with Jersey steers consuming the finishing diet with a greater energy density (Lehmkuler and Ramos, 2008). In agreement, implanted Jersey steers fed steam-flaked corn finishing diets with either 12% or 24% roughage (NE_g = 1.54 vs. 1.42 Mcal/kg) for 383 d had no differences for HCW, DP, and LMA, but lesser marbling scores and BF thicknesses when consuming the 24% roughage diet compared with the 12% roughage diet (Arnett et al., 2012). In disagreement, Jiang et al. (2013) reported greater ADG, final BW, HCW, and LMA, but no differences in BF thickness for Jersey steers (implanted and non-implanted) fed a dry-rolled corn diet with 15% roughage compared with a 30% roughage. This disagreement may be due to differences in the energy density of the diets fed across the three studies, as finishing diets fed by Jiang et al. (2013) had a NE_g of 1.22 vs. 1.12 Mcal/kg, finishing diets fed by Arnett et al. (2012) had a NE_g of 1.54 vs. 1.42 Mcal/kg, and the finishing diet fed by Lehmkuler and Ramos (2008) had a NE_g of 1.44 Mcal/kg. Therefore, Jersey steers fed finishing diets with NE_g > 1.4 Mcal/kg demonstrated no difference in finishing performance, but carcasses had less fat deposition when roughage concentration was greater. However, when feeding Jersey steers finishing diets with NE_g < 1.4 Mcal/kg, greater roughage concentrations resulted in less desirable finishing performance and LMA.

As with other breeds of cattle, implanting Jersey steers improved finishing cattle performance compared with non-implanted Jersey steers. Preliminary data demonstrated improvements of 9.6% for final BW, 13.2% for ADG, 11.3% for DMI, and 7.7% for G:F when Jersey steers were implanted six times compared with non-implanted Jersey steers (Kirkpatrick et al., 2019). Jersey steers implanted six times during the feeding period had an 11% greater HCW, and a 10.3 cm^2 greater LMA, with no difference for BF thickness and less KPH fat by 2.5% compared with non-implanted Jersey steers (Pillmore et al., 2019). However, implanting Jersey steers every 70 d with Revalor-200 over the course of the 420-d feeding trial reduced marbling scores compared with non-implanted Jersey steers (Small[20] vs. Moderate[80]; Pillmore et al., 2019). Implanting Jersey steers six times over the course of the feeding period did not significantly increase the muscle to bone ratio (2.54:1 vs. 2.34:1) but did increase the muscle to fat ratio (4.05:1 vs. 2.68:1) of carcasses compared with carcasses from non-implanted Jersey steers (Wesley et al., 2019). Total carcass fat yield was less (15.1% vs. 20.2%), total red meat yield was numerically greater (59.0% vs. 53.9%), while total bone yield was not different (23.0% vs. 22.8%) due to implanting in Jersey steers (Wesley et al., 2019). These yields for carcass fat, red meat, and bone agree with those reported by Jaborek et al. (2019a) for non-implanted Jersey steers (24.1%, 54.0%, 21.0%, respectively). In addition, Jersey steers that were not implanted had muscle to bone and muscle to fat ratios of 2.59:1 and 2.19:1, respectively (Jaborek et al., 2019a).

Jersey beef is well known for its excellent eating quality characteristics. Jersey ribeye and striploin steaks are reportedly "very tender", by USDA standards (ASTM, 2011), with WBSF measurements typically less than 3.0 kg (Arnett et al., 2012; Johnston, 2014; Jaborek et al., 2019a). Compared with commodity beef striploin steaks from the Longissimus lumborum (50% high select and 50% low choice), striploin steaks from Jersey steers had greater trained sensory panel scores indicating superior tenderness, juiciness, beef flavor, and overall acceptability (Arnett et al., 2012). In addition, consumer sensory panel scores rated Jersey striploin steaks with a greater overall acceptability compared with commodity striploin steaks (Arnett et al., 2012).

Raising Jersey-influenced cattle for beef production can be economically challenging due to the expected reductions in ADG, mature carcass weight, and muscle to bone ratio compared with other breeds of cattle. However, Jersey-influenced cattle produce beef with excellent eating quality due to a greater marbling ability compared with other breeds of cattle (Koch et al., 1976). Therefore, Jersey-influenced cattle are likely to be more competitive in niche markets that emphasize beef quality characteristics desired by consumers compared with the commodity beef market. A combination of management strategies, such as crossbreeding with a terminal beef sire that excels in growth and muscling ability and growth-promoting technology use (e.g., hormonal implants and β-agonists) are likely needed for Jersey influenced cattle to be more competitive in the commodity beef market.

United States Beef × Dairy Crossbreeding

Mating a beef bull and a dairy cow for the production of a crossbred beef × dairy calf has been a popular topic of discussion and practice in the U.S. dairy and beef industries during recent years. In the U.S., the concept of beef × dairy crossbreeding for the production of cattle with a greater beef producing ability, relative to dairy-type cattle, is a strategy that is still gaining momentum whereas other countries around the world have used the strategy in dairy herds for decades. Over the years, there have been multiple occasions in the U.S. when beef × dairy crossbreeding strategies have been investigated.

Experimental station research reports dating back to the 1920s demonstrate the interest in the concept of a beef × dairy crossbreeding. However, the intent of these research proposals was to produce a calf for beef production while having a cow that could produce sufficient milk to raise multiple calves *and* milk that could be made available for human consumption (Fuller, 1928). Later on, research priorities investigating the beef × dairy crossbreeding strategy shifted and were focused on determining the effects of heterosis for the optimal beef animal (Boyd and Hafs, 1965; Pahnish et al., 1969; Urick et al., 1974; Bertrand et al., 1983). Current beef × dairy crossbreeding strategies are being implemented on dairy farms to add value to the calves being produced while improving upon the beef characteristics of the straightbred dairy steer. Recent reports demonstrate that crossbred male beef × dairy calves are more valuable than the straightbred male dairy calf (+$34.58/45.36 kg BW) in the U.S. (McCabe et al., 2022). However, the value of beef × dairy calves through the entire beef production system, from birth to consumption, remains uncertain.

An extensive review of beef × dairy crossbreeding highlights the recent U.S. beef and dairy trends that have led to the rapid adoption of beef × dairy crossbreeding in U.S. dairy farms (Basiel and Felix, 2022). A combination of factors including a rebounding beef cow population after the 2011/2012 western droughts and one of the nation's largest beef packing plants deciding to terminate the slaughter of dairy cattle in 2017 severely impacted the value of male dairy calves (McKendree et al., 2020). In addition, milk prices were low and the increased use of female sexed semen for rapid genetic advancement on dairy farms quickly created a surplus of dairy heifers that were too expensive for many dairy producers to keep and raise. Thus, in 2018, many dairy operations quickly adopted breeding a proportion of the dairy cows, particularly the older genetically inferior cows, with beef semen to add value to the by-product dairy calves. As a result, domestic beef semen sales in the U.S. have increased 242% from 2.5 million in 2017 to 8.7 million in 2021 (NAAB, 2022).

Presently, few controlled studies have investigated the beef × dairy crossbreeding strategy, particularly with offspring produced by Holstein cows (Basiel et al., 2021). However, as a result of the inferior value of male Jersey calves, research has investigated implementing a beef × dairy crossbreeding strategy with Jersey cows. Crossbred Jersey steers sired by Angus, SimAngus, and Red Wagyu sires and raised to be sold into a niche market (e.g., non-hormone treated cattle) demonstrated a greater ADG (14%–27%), final BW (6%–10%), and occasionally DMI (2%–16%) and G:F (8%–15%; Jaborek et al., 2019a) compared with purebred Jersey steers. Crossbred Jersey steers had a greater HCW (13–30 kg), DP (2.0–3.0 percentage units), BF thickness (0.1–0.5 cm), marbling score, and less kidney fat (1.5–2.6 percentage units) compared with purebred Jersey steers. SimAngus- and Red Wagyu-sired steers had a greater total red meat yield compared with the crossbred Angus-sired and purebred Jersey steers (57.6 and 57.3 vs. 54.7 and 54.0% of HCW, respectively). All Jersey influenced steers in the study produced ribeye steaks with WBSF values below 3.4 kg after 7 d post slaughter (Jaborek et al., 2019a), thus qualifying them for "very tender" USDA labeling claims (ASTM, 2011).

In the beef × dairy crossbreeding strategy, crossbred heifers are also going to be produced unless male sexed semen is used. Crossbred Jersey heifers had a lesser ADG, DMI, G:F, and final BW compared with Jersey steers (Jaborek et al., 2019b). In addition, crossbred Jersey heifer carcasses finished with a lighter HCW, but a greater amount of BF and kidney fat compared with crossbred Jersey steer carcasses. Crossbred Jersey heifer carcasses yielded 1.45% less total red meat, 3.22% more fat, and 1.35% less bone compared with crossbred Jersey steer carcasses. The lesser red meat yield produced by purebred and crossbred Jersey steers and heifers (Jaborek et al., 2019a, 2019b; 2020) demonstrates the need to select for growth and muscling from a terminal beef sire, in combination with the use of growth-promoting technologies, in order for them to compete in the commodity beef market with cattle from beef breeds.

The review by Basiel and Felix (2022) offers excellent advice regarding the selection criteria of beef sires for matings with dairy cows in the beef × dairy crossbreeding strategy. The authors agree that beef sires should be selected to complement the weaknesses of the dairy steer, such as selecting beef sires with expected progeny differences (EPD) that are superior for weaning weight, yearling weight, and ribeye area. In addition, selection for marbling ability should be emphasized to generate beef × dairy calves that can excel in the U.S. beef industry. With the dairy producer in mind, beef sires selected for use in a beef × dairy crossbreeding strategy often consider calving ease and fertility traits as well. The EPD of beef sires of different breeds can be compared using across breed EPD adjustment factors produced by the U.S. Meat Animal Research Center to help with beef sire selection decisions (USMARC, 2022). However, there are currently few recommendations or comparisons available across dairy and beef breeds. Currently in the U.S., EPD indices are being created to identify beef sires that may be better suited for breeding with dairy cows for the production of beef × dairy calves. However, these indices rely heavily on the beef sire's beef × beef progeny with limited beef × dairy progeny data for support.

Future Research Needs for Dairy Cattle Used for Beef Production

A common highlight of this review has been the mention of the inferior muscling or a lesser muscle to bone ratio from dairy steers raised for beef when compared with beef steers. Currently, there are no selection criteria for retail or red meat yield from dairy cattle. Both the dairy and beef industries can continue to refine their management strategies, by selecting better beef bulls to mate at the dairy farm and by using growth-promoting technologies in beef production systems, to improve the efficiency of gain and total red meat yield while maintaining marbling deposition. One new solution that has been discussed in this review is the shift towards producing or incorporating of beef × dairy cattle from the dairy herd. Presently, research focused on beef × dairy cattle in U.S. production systems is greatly needed, as there is little current scientific data available. Beef sire selection and the effect of heterosis from the crossbred mating will likely influence the performance and characteristics of the beef × dairy crossbred calf. Moderately to highly heritable traits, such as growth and carcass traits, are more likely to be passed on to the offspring, but less likely to experience improvements due to heterosis, while heterosis is expected to be greater for less heritable traits, such as calf survivability and fertility traits (Koots et al., 1994). However, the industry must recognize the current management practices applied to straightbred dairy calves raised for beef and those applied to beef calves may not always be appropriate for crossbred beef × dairy calves and will need to be reevaluated.

While not within the scope of this feedlot focused manuscript, we recognize that prior calf management subsequently affects future calf health, growth, finishing cattle performance, and carcass characteristics. However, very few dairy calf studies aim to determine the effects of the scientific treatments imposed during early calfhood on future performance of male dairy calves. Thus, there is a disconnect between the dairy and beef industries that can be explored with research to provide additional information on the impacts of early calfhood management on subsequent male dairy calf performance in the feedlot. Future research should improve upon past reviews of early calfhood management of Holstein steers sent to the feedlot (Chester-Jones et al., 1998). A 100-year review of calf nutrition and management offers information on various topics such as colostrum (Godden et al., 2019), milk replacer, energy, protein, vitamin, and mineral requirements, diet energy density, calf starter, forage inclusion (Suarez-Mena et al., 2016), weaning, housing, behavior, and rumen development (Kertz et al., 2017). Likewise, the National Academies of Sciences, Engineering, and Medicine (NASEM) has recently revised the nutrient requirements of dairy cattle, which contains a chapter on the nutrient requirements of the young calf (NASEM, 2021).

According to the most recent Elanco Liver Check Service data, Holstein steers have a greater incidence of liver abscesses compared with beef steers and heifers (Reinhardt and Hubbert, 2015). However, the liver abscess incidence rate of Holstein and beef steers has not been compared in a controlled experiment to account for management and nutritional differences. Nonetheless, the average incidence of liver abscesses for Holstein steers has increased from 30% up to more than 40% from 2010 to 2016, while the average incidence rate of approximately 15% and 12% for beef steers and heifers, respectively, has not changed (Armachawadi and Nagaraja, 2016). A more recent assessment of liver abscess incidences at major beef processing facilities were 18%, 19%, and 25% for fed beef steers, fed beef heifers, and Holstein steers, respectively (Herrick et al., 2022). In addition, Holstein steers had a greater percentage of livers that scored more severe, A+ and adhered to the diaphragm or other internal viscera (Herrick et al., 2022). An increased incidence of liver abscesses and greater severity of liver abscesses from Holstein steers would result in a greater economic loss due to the condemned livers, organs, and excess trimming that is required. Liver abscess incidence is regionally influenced in the U.S., particularly with Holstein steers (Reinhardt and Hubbert, 2015; Herrick et al., 2022). Reinhardt and Hubbert (2015) reported that data from Elanco's Liver Check Service identified greater liver abscess rates for Holstein steers raised in the Central Plains (22%), while liver abscess rates were lower for Holstein steers raised in the Midwest, Southern Plains, and Southwest (13%), and intermediate for the Northern Plains and Northwest U.S (19%).

The formation of liver abscesses is commonly attributed to damage of the rumen epithelium that allows bacteria, most commonly *Fusobacterium necrophorum*, *Trueperella pyogenes*, and *Salmonella enterica*, to enter into the portal blood stream and infect the liver (Amachawadi et al., 2017; Herrick et al., 2022). Many accept forage/roughage concentration and form are contributing factors for the development of liver abscesses because more forage in the diet can increase ruminal pH to reduce ruminal epithelium insult (Zinn and Plascencia, 1996; Reinhardt and Hubbert, 2015). Mertens (2002) reported that the optimum physically effective neutral detergent fiber (NDF) value needed in the diet to reduce liver abscesses was about 22%. However, there have been conflicting results when investigating the effects of dietary forage or NDF concentrations on the subsequent occurrence of liver abscesses at slaughter, possibly negated by the use of tylosin in some studies (Gentry et al., 2016; Jennings et al., 2021; Pereira et al., 2021; Zellmer, 2021). Interestingly, grain processing has only demonstrated a minor association with the incidence of liver abscesses according to a review by Reinhardt and Hubbert (2015). In addition, due to a greater amount of time consuming a high-energy finishing diet to achieve a desired slaughter endpoint, Holstein steers experience a greater opportunity over time to experience acidosis (upper and lower gastrointestinal tract) that can lead to the development of liver abscesses. It is possible behavioral differences, such as grooming and wood chewing, could contribute to or be a response to rumen epithelial damage and subsequent development of liver abscesses in Holsteins compared with steers from beef breeds, but the effect of these behaviors on liver abscess development have not been studied at this time. Overall, the occurrence of liver abscesses is a major economic loss for the beef industry. Future research will be needed to determine the cause of liver abscesses so management strategies to be designed and implemented to reduce liver abscess prevalence in the beef industry.

In conclusion, by-product dairy calves raised for beef production contribute a significant number of cattle and economic value to the U.S. beef supply chain. Dairy cattle raised for beef production offer unique opportunities such as uniform group finishing cattle performance and carcass characteristics. Additionally, Holstein and Jersey steers are recognized for their ability to achieve premium USDA QG and beef eating characteristics, such as flavor and tenderness. However, Holstein and Jersey steers experience unique challenges such as a lesser G:F and total red meat yield compared with steers from beef breeds. The use of growth-promoting technologies can help close the gap experienced between dairy cattle raised for beef production and cattle from beef breeds. The adoption of beef × dairy crossbreeding strategies in dairy farms offers the opportunity to improve the beef characteristics of by-product dairy calves and resulting beef production system efficiency. However, controlled research is still needed to confirm these improvements in beef production efficiency from the crossbred beef × dairy calf. Further research is also needed for determining the effects of early calfhood management strategies on subsequent finishing cattle performance and carcass characteristics, as well as the reason for a greater liver abscess rate in Holstein steers compared with steers from beef breeds.

Conflict of Interest Statement

The authors declare no conflict of interest.

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