Translational Animal Science, 2022, **6**, 1–7
https://doi.org/10.1093/tas/txac027
Advance access publication 22 February 2022
Symposia

Invited review: a carcass and meat perspective of crossbred beef × dairy cattle

Blake A. Foraker, Jenna L. Frink, and Dale R. Woerner[1]

Department of Animal and Food Sciences, Texas Tech University, Lubbock, TX 79409, USA
[1]Corresponding author: dale.woerner@ttu.edu

ABSTRACT

Crossbreeding dairy cows with beef sires has greatly altered the consist of U.S. dairy-influenced slaughter cattle and generated an influx of crossbred beef × dairy cattle to the U.S. fed beef slaughter supply in 2021. This review provides a summary of our observations of carcass and meat traits in the recent U.S. beef × dairy crossbred population and, based on these observations, exposes future opportunities for consideration. Strip loin steaks from beef × dairy cattle can be marketed alongside conventional beef products in retail display without consumer discrimination based on color or steak shape previously experienced in steaks from straightbred dairy cattle. Additionally, beef from crossbred beef × dairy cattle cannot be discriminated against for eating quality attributes (tenderness, flavor, and juiciness) as it exhibits similar, if not improved, performance of these attributes to beef from conventional beef cattle. We have also demonstrated that live expression of beef-type versus dairy-type character within the beef × dairy crossbred population has minimal effect on eating quality. With proper genetic selection and management, crossbred beef × dairy cattle can capture carcass premiums from an optimal combination of carcass quality (marbling) and red meat yield. Future beef × dairy crossbred mating and management systems should emphasize increases in total carcass muscling and reductions in liver abscess prevalence. A story of quality, sustainability, and traceability in the large and constant supply of beef from crossbred beef × dairy cattle may present profitable branding and marketing opportunities for these products.

Key words: beef-on-dairy, color, flavor, muscling, tenderness, yield

INTRODUCTION

Crossbreeding beef sires to dairy cows, commonly termed "beef-on-dairy," has garnered recent attention and debate within the United States (U.S.) beef and dairy industries, and there is much to learn about how the offspring perform live and in the beef. Even though beef × dairy crossbreds have been in our industry for many years, the seemingly widespread implementation of this breeding practice in the U.S. began around the year 2018. From 2013 to 2017, annual domestic U.S. semen sales were relatively steady for both dairy (23.1 [SD 0.46] million units) and beef (2.3 [SD 0.34] million units) semen (NAAB, 2021). Compared to these 5-year averages, in 2020, sales of beef semen were 4.9 million units (200%) greater while sales of dairy semen were 4.7 million units less (NAAB, 2021). Considering that the majority of U.S. dairy cows were mated with artificial insemination and that the majority of U.S. beef cows were not, these changes in semen sales have been attributed to beef × dairy crossbreeding, especially considering that the U.S. dairy cow inventory has remained constant between 9.2 and 9.5 million cows for each of the past 10 years (McWhorter et al., 2020; USDA-NASS, 2021a, 2021b). Assuming 1 calf born per dairy cow each year, a bull to heifer calf ratio of 1:1, a female replacement rate of 35%, and marginal death loss, it is reasonable that 5 million dairy-influenced progeny, whether straightbred dairy or crossbred beef × dairy, could enter the U.S. fed beef slaughter supply, which totals approximately 25 million cattle annually (USDA-NASS, 2021b). Today, it is difficult to estimate how many dairy-influenced slaughter cattle are straightbred dairy versus crossbred beef × dairy because these classifications are not publicly reported. Beef packers have stated, however, that the number of beef × dairy crossbreds slaughtered in 2020 and 2021 was dramatically greater than in previous years. Stronghold of cattle markets by terminal segments (i.e., beef packers) in 2021 further underpins the relevancy of conversation about carcass traits and beef value in crossbred beef × dairy cattle.

The U.S. dairy industry, even more than the U.S. beef industry, has achieved a level of recent technological advancement in reproduction (e.g., artificial insemination and sexed semen), genetic evaluation (e.g., genomic sequencing), and recordkeeping (e.g., lactation and reproduction performance) that has allowed for the identification of superior mating scenarios to maximize milk production and (or) quality. Correspondingly, dairies now have tools to identify genotypically and phenotypically superior dams from which replacement females will be produced and retained, which has created a viable opportunity for beef × dairy crossbreeding in the remainder of the cowherd. Specialization in heifer raising and management by some dairies has allowed other dairies to completely outsource their replacement females from these specialized operations. Moreover, volatility in milk prices and recent low milk prices have prompted dairy farmers to identify other streams of revenue, like crossbred beef × dairy calves that garner a noteworthy premium over straightbred dairy calves, which were once viewed as a dairy by-product

Received December 1, 2021 Accepted February 21, 2022.

(McCabe et al., 2022). Other factors have also contributed to recent demand for crossbreeding beef sires to dairy cows, including heterotic effects on calf health (Snowder et al., 2005), low-cost and high fertility beef semen (McWhorter et al., 2020), and packer signals discriminating against straightbred dairy cattle (McKendree et al., 2020).

The recent shift in U.S. dairy-influenced slaughter cattle away from straightbred dairy breeding and towards beef × dairy crossbreds will likely continue, such that beef × dairy crossbreds may, and perhaps currently do, outnumber straightbred dairy slaughter cattle. Value of straightbred dairy slaughter cattle is generally well understood in the beef supply chain (McKendree et al., 2020). However, crossbreeding beef and dairy breeds has raised questions about appropriate value of resulting terminal progeny, especially from a meat and carcass perspective. Minimal peer-reviewed research has been published recently on beef × dairy crossbreds in the U.S. Most U.S. research conducted on beef × dairy crossbreeding was done nearly 30 or more years ago using cattle genetics that are not likely relevant today (BreDahl, 1970; Bertrand et al., 1983; Cartwright, 1983). Beef × dairy crossbreeding has occurred for some time outside of the U.S., and recent peer-reviewed research of the practice has been reported (Dal Zotto et al., 2009; Keane and Moloney, 2010; Huuskonen et al., 2013; Berry, 2021). However, conclusions drawn from studies on cattle populations in countries outside of the U.S. may not be entirely applicable to the U.S. production system because of vast differences between countries in management and genetics.

With the rapid growth of beef × dairy crossbreds entering the U.S. beef supply chain, entities purchasing, processing, and marketing beef products, including packers, foodservice purveyors, retailers, and branded program managers, had questions about the compositional and quality differences in beef resulting from these cattle. As a result, at Texas Tech, much of our research has centered on comparing beef × dairy crossbreds to their parental breed types—straightbred dairy and conventional beef. Realizing that breed and individual sire is important for many factors related to carcass composition and meat quality, our data were based on samples that represented common industry practices at the time of their collection. Specifically, samples from straightbred dairy cattle were predominantly, if not wholly, of Holstein composition. Samples from crossbred beef × dairy cattle were predominantly from sires of Angus, Simmental, Limousin, or any of their crossbred combinations and from dams of Holstein or Holstein × Jersey. Samples from conventional beef cattle were representative of common breeds and (or) crossbreds in the beef industry, including Angus, Charolais, Simmental, Limousin, and Hereford. This review provides a summary of our observations of carcass and meat traits in the recent U.S. beef × dairy crossbred population and, based on these observations, exposes future opportunities for consideration.

CONSUMER ACCEPTANCE AND EATING SATISFACTION

A common perception by beef producers and consumers alike is that the quality of beef produced from dairy cattle is inferior to conventional beef for most attributes, including taste and tenderness. This perception is inaccurate, especially for eating quality attributes that influence consumer satisfaction. Furthermore, consumers do not often realize that many beef products, particularly those at the food service level, have been marketed on a commodity basis over the past 10 to 20 years, irrespective of dairy-influence. We have aimed to quantify the effects of cattle breed type, with particular emphasis on beef × dairy crossbreds, on important factors related to consumer preferences and, indirectly, product value.

For a retailer, beef products—namely strip loin steaks and ribeye steaks—from dairy cattle have presented two important challenges: 1) color stability at retail display, and 2) steak shape and angularity. These concerns have been unquestionably evident in straightbred dairy cattle and are primary reasons why steaks from dairy cattle have not been effectively merchandised alongside steaks from conventional beef cattle in a retail case. To partially explain this phenomenon, we showed that longissimus muscle from dairy cattle exhibited a greater proportion of oxidative muscle fibers than conventional beef cattle, a result that has been reviewed and supported in literature (Figure 1; Picard et al., 2020). Accordingly, greater oxidative metabolism in longissimus muscle from dairy cattle contributed to their steaks being darker in overall color—even on the first day of retail display—and discoloring at a faster rate compared to steaks from conventional beef cattle. Moreover, steaks from straightbred dairy cattle exhibited a more triangular shape and smaller total surface area compared to more symmetrical and larger conventional beef steaks (Figure 2).

In two separate studies, we identified that retail color display and dimensionality of strip loin steaks from crossbred beef × dairy cattle were a much lesser concern, if at all, than in straightbred dairy cattle. At 60 h of retail display, dairy steaks reached 20% surface area discoloration, a level of discoloration at which consumers discriminate (Hood and Riordan, 1973). Conversely, conventional beef and beef × dairy steaks, which were not different from each other in color stability, achieved a level of 20% discoloration at 84 h of retail display.

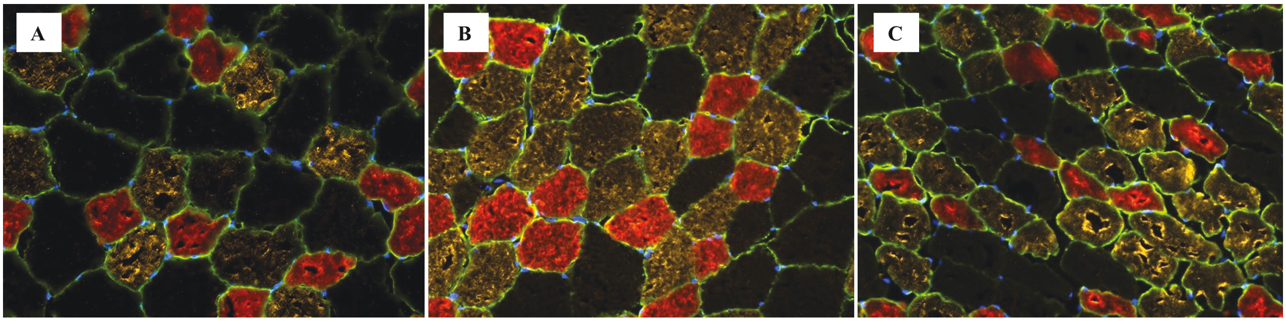

Figure 1. Muscle fiber cross-sections stained by myosin heavy chain (MHC) isoform (MHC-I, oxidative = red; MHC-IIa, oxiglycolytic = yellow; MHC-IIx, glycolytic = black) from different cattle types: (A) conventional beef; (B) crossbred beef × dairy; (C) dairy.

A separate study confirmed our observation that, on average, strip loin steaks from crossbreed beef × dairy cattle reached a level of 20% discoloration at approximately 84 h of retail display. Additionally, beef × dairy strip loin steaks were more similar to conventional beef strip loin steaks for all measures of steak width than dairy steaks, especially in lateral steak regions most prone to angularity (Figure 2). We also observed minimal differences in steak shape and dimension across the strip loin, from the 13th rib region to more posterior regions (near the sirloin), between crossbred beef × dairy cattle that exhibited large differences in live animal expression of beef-type or dairy-type (Figure 3).

Despite their display challenges at the retail level, dairy steaks are often utilized by many restaurants because of their consistency and high level of performance in eating quality. In our consumer taste panel, steaks from dairy cattle were rated by consumers as most tender when compared to conventional beef and beef × dairy steaks at equal degrees of marbling from Slight to Slightly Abundant. Consumers rated steaks from beef × dairy crossbreds numerically intermediate for tenderness and flavor compared to dairy and conventional beef steaks. Still, overall consumer acceptance was not different between steaks from conventional beef, beef × dairy, and dairy cattle. Evaluation of separate steaks from the same cattle by trained experts for tenderness, juiciness, and specific flavor notes indicated that the influence of dairy breeding may enhance some eating quality attributes. Trained panelists—with a more acute palate than everyday consumers—distinguished strip loin steaks from dairy and crossbred beef × dairy cattle as more tender and more intense in fat-like and buttery flavor than steaks from conventional beef cattle. Similar to consumer and trained panelist ratings for tenderness, shear force values (Warner-Bratzler and slice) for beef × dairy steaks were intermediate to dairy (least) and conventional beef (greatest) steaks. Furthermore, trained panelists could not identify differences in steaks from crossbred beef × dairy cattle with largely divergent beef-type versus dairy-type, suggesting consistency in eating quality within the crossbred beef × dairy population. When steaks from crossbred beef × dairy cattle were aged 14 d postmortem, frozen, and thawed for cooking, 85% of these steaks met or exceeded minimum thresholds to qualify for the USDA Certified Tender claim (less than 3.9 kg Warner Bratzler shear force; ASTM, 2011).

CARCASS PERFORMANCE

Carcass value contributes greatly to cattle value in other segments of the beef supply chain, especially when packers realize a more substantial margin compared to these other segments, which has been the case in 2021. Before its widespread implementation, limited use of beef × dairy crossbreeding produced calves that were often mixed with commodity beef calves and (or) marketed with their dairy-influenced identity being untold. Breeding decisions in early adoption of beef × dairy crossbreeding focused on production of black-hided calves to capture premiums from branded programs specifying an Angus phenotype. Thus, from 2015 to 2018, many beef × dairy crossbreds garnered substantial carcass value compared to their straightbred dairy counterparts, especially with an all-time high discount for dairy carcasses and a stance by some packers to refuse dairy slaughter cattle (McKendree et al., 2020). Recent influx of beef × dairy crossbreds to the market has made beef × dairy identity well-known, and hide color, although still important for some branded beef programs, seems to be less emphasized in the marketplace. Correspondingly, packers have evaluated both positives and

Figure 2. Steaks from the 13th rib region of strip loins from different cattle types: (A) conventional beef; (B) crossbred beef × dairy; (C) dairy.

Figure 3. Largely divergent expression of beef- versus dairy-type in SimAngus × Holstein cattle from the same contemporary group (i.e., similar age, similar calf management, and same feedlot pen).

negatives of the contribution of beef × dairy crossbreds to the beef supply chain. Most recently, some packers exercised a universal discount on crossbred beef × dairy cattle because of key factors contributing to value losses.

Liver abscesses, and their associated financial losses, are a major contributor to recent packer discounts imposed on crossbred beef × dairy cattle. Substantial financial losses, above and beyond those of abscessed livers, occur from adhesions of severely diseased livers to high-value muscles, like diaphragm (merchandised as outside skirt). Liver abscesses also impact efficiency and cost of production, as contamination of other viscera and carcass tissues from open liver abscesses across multiple cattle of the same processing lot results in slower processing line speeds to accommodate additional trimming. Prevalence of liver abscesses is routinely reported as greater in straightbred dairy cattle (50% to 80%) than conventional beef cattle (15% to 30%), which is why many packers only harvest straightbred dairy cattle in small groups, if at all (Amachawadi and Nagaraja, 2016; personal communications with beef packers). It is not well understood why the incidence of liver abscesses is greater in dairy cattle compared to conventional beef cattle (Amachawadi and Nagaraja, 2016). However, it is generally accepted that feeding a high concentrate diet for an extended time, which is common in dairy cattle, increases the likelihood for ruminal acidosis and subsequent liver abscess development (Rezac et al., 2014). Still, liver abscesses have been reported to occur in 10% or less of some straightbred dairy cattle fed in southwestern regions of the U.S., suggesting that diet or breed type alone cannot explain high liver condemnation rates in the dairy cattle population (Reinhardt and Hubbert, 2015; Amachawadi and Nagaraja, 2016). Data collected by our research group suggest that beef × dairy crossbreds exhibit an intermediate liver abscess rate (40 to 60%) to their parental breed types, although wide variations between feedlots have been observed. Additional research of liver abscesses and their specificity in certain types of cattle populations, like those of dairy-influence, is needed.

Red meat yield is a major concern for beef processors and another primary reason for packer discounts of beef × dairy cattle. At equal live weights and as it relates to saleable carcass tissue, dairy cattle often receive discounts to conventional beef cattle for two mutually exclusive reasons: 1) their conversion of live weight to carcass weight is lower (dressing percentage), and 2) their conversion of carcass weight to saleable whole muscle cuts is generally lower (muscle-to-bone ratio) when compared at similar levels of fatness. Lower muscle-to-bone ratio in dairy cattle versus beef cattle is generally accepted because of large differences in muscle, which is a denser and more abundant carcass tissue than fat and bone related to skeletal frame between cattle types. Our studies have shown that, at a constant hot carcass weight, beef × dairy crossbreds exhibit intermediate ribeye area size and intermediate 12th rib fat thickness to dairy and conventional beef cattle. Both dairy and beef × dairy carcasses possessed a one-unit greater percentage of kidney, pelvic, and heart fat (on a hot carcass weight basis) than conventional beef carcasses. Dressing percentage of beef × dairy crossbreds has generally averaged 63.0%, a substantial improvement compared to common USDA Agricultural Marketing Service reports of 61.0% in dairy cattle (63.5% in conventional beef cattle). However, a focus on dressing percentage might be much less pertinent when the contribution of fat to carcass weight is considered, especially in excessively fat cattle (Berg and Butterfield, 1976). With more muscle than dairy cattle and less fat than conventional beef cattle, beef × dairy cattle produce a lesser proportion of Yield Grade 4 and 5 carcasses than conventional beef cattle and a greater proportion of Yield Grade 1 and 2 carcasses than dairy cattle. However, like many, we question the ability of USDA Yield Grades to accurately reflect percentage red meat yield on an individual carcass basis. When we evaluated crossbred beef × dairy cattle of largely divergent beef-type versus dairy-type character, even at similar carcass weights, no difference in ribeye area existed; however, large differences were noted in expression of round muscling (Figure 4). Further metrics are

Figure 4. Round muscling of carcasses from beef × dairy crossbred cattle with largely divergent live expression of beef- versus dairy-type.

needed to assess carcass muscularity and its contribution to overall carcass yield in all cattle and not just those of dairy-influence. We conducted a separate whole carcass cutout study comparing conventional beef, crossbred beef × dairy, and straightbred dairy cattle. Beef × dairy carcasses produced slightly less saleable red meat yield than conventional beef carcasses but much greater yield than straightbred dairy carcasses. A greater percent bone in crossbred beef × dairy carcasses was the primary reason for their slight disadvantage in red meat yield to conventional beef carcasses. Consequently, cattle populations predisposed to possessing a lighter muscled phenotype, such as those with dairy-influence, should emphasize muscling development in mating scenarios for a terminal production system. When muscling is not emphasized, some beef × dairy crossbreds in the system are just as inferior, if not worse, for red meat yield as straightbred dairy cattle.

At an expense to muscle and added days on high-concentrate feed, dairy-influenced cattle have generally and positively contributed to the U.S. Quality Grade distribution, such that some estimates have reported dairy carcasses comprise 32% of the USDA Prime grade (Boykin et al., 2017). Our data indicate that the positive influence of dairy breeding on Quality Grade performance is not entirely negated in beef × dairy crossbred cattle, as an appreciable proportion of beef × dairy carcasses (between 35% and 45%) exhibit sufficient marbling (Modest or greater) to meet qualification for branded beef programs. However, a shift in the consist of dairy-influenced cattle from straightbred dairy to crossbred beef × dairy will likely have a negative effect on national percentage of very high quality (USDA Prime) carcasses because of a dilution effect in marbling relative to ribeye size and a compositional shift in muscle fiber composition towards more glycolytic pathways that are less favorable for marbling development (Calkins et al., 1981). Correspondingly, future breeding decisions for beef × dairy crossbreds should emphasize both yield and quality traits for optimal terminal progeny.

OPPORTUNITIES FOR IMPROVEMENT

Inefficiencies associated with growing, feeding, and slaughtering straightbred dairy cattle for terminal beef production are mitigated by replacing the straightbred dairy cattle population with beef × dairy crossbreds. The positive influence of beef genetics in beef × dairy crossbreds results in improved animal health, lower death loss, fewer days on feed, greater feed efficiency, and increased carcass yields compared to straightbred dairy cattle, making the practice of crossbreeding beef × dairy largely more sustainable than production of straightbred dairy calves. Further adding to their sustainability benefit over straightbred dairy cattle, crossbred beef × dairy cattle produce beef that has a greater shelf-life before discoloration makes the product non-saleable. Additionally, our data have demonstrated that the influence of dairy genetics has positive effects on eating quality in beef × dairy crossbreds. Regardless of the expression of beef-type or dairy-type character in crossbred beef × dairy cattle, their beef will produce a consistent eating quality. Thus, because beef × dairy crossbreds produce a high-quality, consistent beef product in a more sustainable production system than straightbred dairy cattle, all segments of the beef supply chain should emphasize production of optimal beef × dairy cattle (Figure 5).

Opportunities to make dairy-influenced cattle better with the addition of beef genetics in a crossbreeding scenario hold noteworthy implications for beef genetic suppliers, including seedstock producers. Determining an ideal individual sire—rather than an ideal sire breed—to complement the mating system may prove more efficacious in making beef × dairy crossbreds better, especially when large numbers of progeny from a single sire on a single dairy can be produced in

Dressing percentage	12th rib fat thickness	Ribeye area	USDA yield grade	USDA quality grade
65.4%	1.16 cm	115 cm^2	2.4	Choice

Figure 5. Optimal crossbred SimAngus × Holstein steer.

one generation and when a system exists to track progeny performance. Artificial selection and genetic improvements within many different cattle breeds have created as much variation within breeds as between breeds for carcass traits (Wheeler et al., 1996). Additionally, using a single sire may improve uniformity of calf crop compared to using many sires, even if they are full-siblings (Gosey, 1997). It should be noted that the best sire for a beef × dairy scenario may not be the best candidate for mating beef cows. Sire selection for beef × dairy should firstly emphasize acceptable fertility and birthweight because of their influence in cow performance at the dairy; secondarily, carcass merit for both muscularity and marbling should receive consideration. Our data support that ribeye area alone is a relatively poor selection criterion for estimation of muscling in other carcass regions; thus, live animal appearance and beef-type, with particular attention to muscling of the hindquarter, should receive assessment when determining which beef sires to mate to dairy cows. The problem of liver abscesses needs addressed industry-wide and, while more prevalent in dairy-influenced cattle, is not specific to this population alone. Calf ranches and feedlots should consider practices that improve ruminal health when managing beef × dairy crossbreds.

As the beef industry continues to experience pressure from governmental regulation, consumer skepticism, and export markets, a fully traceable cattle supply may become an important factor of economic value in the beef supply chain. Dairies generally keep robust records of calves born and cattle inventory; thus, a steady supply of calves from dairies, whether straightbred dairy or beef × dairy crossbred, may present an intrinsic component of traceability that holds value in current or future market systems. While traceability inherent to the dairy production system presents a positive for dairy-influenced calves, large variability in production practices at the calf ranch level has presented animal welfare and performance concerns. Ventures to increase beef × dairy crossbred value should emphasize a total quality management system through the supply chain, especially when ownership spans multiple production stages.

SUMMARY

Crossbred beef × dairy cattle positively contribute to the beef supply chain, especially from a meat and carcass quality perspective, as noted at the consumer, retailer, foodservice, and packer level. Beef products from beef × dairy crossbreds consistently deliver a high level of eating satisfaction and can be marketed alongside conventional beef products without concern. Keen focus is needed to supply dairies with optimal beef genetics that complement the influence of dairy breeding without sacrifice to fertility and calving ease. Improvements in total carcass muscularity and gut condemnation rates will make carcasses of beef × dairy crossbreds more valued in the supply chain. When optimal beef × dairy crossbreds are produced, their beef products offer a story of quality, sustainability, and traceability that might excel in a branded marketing program.

Conflict of interest statement

None declared.

LITERATURE CITED

Amachawadi, R. G., and T. G. Nagaraja. 2016. Liver abscesses in cattle: a review of incidence in Holsteins and of bacteriology and vaccine approaches to control in feedlot cattle. *J. Anim. Sci.* 94:1620–1632. doi:10.2527/jas.2015-0261

ASTM. 2011. *F2925-11 Standard specification for tenderness marketing claims associated with meat cuts derived from beef*. West Conshohocken (PA): American Society for Testing Materials International.

Berg, R. T., and R. M. Butterfield. 1976. *New concepts of cattle growth*. Sydney (NSW, Australia): Sydney University Press.

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

Bertrand, J. K., R. L. Willham, and P. J. Berger. 1983. Beef, dairy and beef × dairy carcass characteristics. *J. Anim. Sci.* 57:1440–1448. doi:10.2527/jas1983.5761440x

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: survey of carcass characteristics through instrument grading assessments. *J. Anim. Sci.* 95:3003–3011. doi:10.2527/jas2017.1544

BreDahl, R. L. 1970. *Beef-dairy crossbreeding: a study of birth traits*. Ames (IA): Iowa State University.

Calkins, C. R., T. R. Dutson, G. C. Smith, Z. L. Carpenter, and G. W. Davis. 1981. Relationship of fiber type composition to marbling and tenderness of bovine muscle. *J. Food Sci.* 46:708–710. doi:10.1111/j.1365-2621.1981.tb15331.x

Cartwright, T. C. 1983. The role of dairy cattle genes in United States beef production. *J. Dairy Sci.* 66:1409–1418. doi:10.3168/jds.S0022-0302(83)81953-5

Dal Zotto, R., M. Penasa, M. de Marchi, M. Cassandro, N. López-Villalobos, and G. Bittante. 2009. Use of crossbreeding with beef bulls in dairy herds: effect on age, body weight, price, and market value of calves sold at livestock auctions. *J. Anim. Sci.* 87:3053–3059. doi:10.2527/jas.2008-1620

Gosey, J. A. 1997. Bull genetics: purebreds, composites, full-sibs and half-sibs. In: *Proceedings of the Range Beef Cow Symposium XV*; p. 1–15.

Hood, D. E., and E. B. Riordan. 1973. Discolouration in prepackaged beef: measurement by reflectance spectrophotometry and shopper discrimination. *Int. J. Food Sci. Technol.* 8:333–343. doi:10.1111/j.1365-2621.1973.tb01721.x

Huuskonen, A., M. Pesonen, H. Kämäräinen, and R. Kauppinen. 2013. A comparison of the growth and carcass traits between dairy and dairy × beef breed crossbred heifers reared for beef production. *J. Anim. Feed Sci.* 22:188–196. doi:10.22358/jafs/65987/2013

Keane, M. G., and A. P. Moloney. 2010. Comparison of pasture and concentrate finishing of Holstein Friesian, Aberdeen Angus × Holstein Friesian and Belgian Blue × Holstein Friesian steers. *Irish J. Agric. Food Res.* 49:11–26. http://www.jstor.org/stable/20788562

McCabe, E. D., M. E. King, K. E. Fike, and K. G. Odde. 2022. Effects of Holstein and beef-dairy cross breed description on the sale price of feeder and weaned calf lots sold through video auctions. *Appl. Anim. Sci.* 38:70–78. doi:10.15232/aas.2021-02215

McKendree, M.G.S., T.L. Saitone, and K.A. Schaefer. 2020. Cattle cycle dynamics in a modern agricultural market: competition in Holstein cattle procurement. In: *Agricultural & Applied Economics Association Annual Meeting*.

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

NAAB. 2021. *Annual reports of semen sales and custom freezing*. NAAB. Available from https://www.naab-css.org/semen-sales.

Picard, B., M. Gagaoua, and M. Gagaoua. 2020. Muscle fiber properties in cattle and their relationships with meat qualities: an overview. *J. Agric. Food Chem.* 68:6021–6039. doi:10.1021/acs.jafc.0c02086

Reinhardt, C. D., and M. E. Hubbert. 2015. Control of liver abscesses in feedlot cattle: a review. *Prof. Anim. Sci.* 31:101–108. doi:10.15232/pas.2014-01364

Rezac, D. J., D. U. Thomson, S. J. Bartle, J. B. Osterstock, F. L. Prouty, and C. D. Reinhardt. 2014. Prevalence, severity, and relationships of lung lesions, liver abnormalities, and rumen health scores measured at slaughter in beef cattle. *J. Anim. Sci.* 92:2595–2602. doi:10.2527/jas.2013-7222

Snowder, G. D., L. D. Van Vleck, L. V. Cundiff, and G. L. Bennett. 2005. Influence of breed, heterozygosity, and disease incidence on estimates of variance components of respiratory disease in preweaned beef calves. *J. Anim. Sci.* 83:1247–1261. doi:10.2527/2005.8361247x

USDA-NASS. 2021a. *Milk production*. Washington (DC): U.S. Department of Agriculture.

USDA-NASS. 2021b. *Cattle*. Washington (DC): U.S. Department of Agriculture.

Wheeler, T. L., L. V. Cundiff, R. M. Koch, and J. D. Crouse. 1996. Characterization of biological types of cattle (Cycle IV): carcass traits and longissimus palatability. *J. Anim. Sci.* 74:1023–1035. doi:10.2527/1996.7451023x