GROWTH PERFORMANCE, CARCASS TRAITS, AND FEEDER CALF VALUE OF BEEF × HOLSTEIN AND HOLSTEIN FEEDLOT STEERS

By

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ABSTRACT

This study evaluated and compared feedlot performance and carcass characteristics of B×HO and HO steers so that subsequent value could be calculated. Beef × Holstein steers did not show improved health in terms of morbidity or mortality when compared with their HO contemporaries. Hip height and frame scores were lower for B×HO, showing this one major packer concern could be improved. Crossbreds had a tendency for greater average daily gain (ADG), as well as having a greater gain-to-feed ratio (G:F), demonstrating that they were more feed efficient than their HO contemporaries. The dry matter intake (DMI) was similar between breed types. Even though the live final weight tended to be lesser for the B×HO, hot carcass weight (HCW) was similar. Similarly, dressing percentage and kidney, pelvic, and heart fat were not different. Fat thickness (FT) and longissimus muscle area (LMA) were greater for the B×HO, with no differences observed for marbling score when compared with the HO. Calculated USDA Yield Grade was lower for B×HO, demonstrating they had greater yield compared with their HO counterparts. In agreement, LMA:HCW was greater for B×HO, further demonstrating their greater yield and muscling compared with the HO steers. Empty body fat was not different (at an average of 28.0%) for the B×HO and HO steers, consistent with the study design to harvest on a similar basis. The USDA Quality Grades were not different for those grading Select or higher. Cost of gain was \$0.17/kg lower for the B×HO. Compared with the HO, the B×HO had a \$11.39/100 kg greater carcass value and, similarly, their breakeven feeder calf cost was \$63.44/100 kg greater. Overall, health and DMI were not different between breed types. Beef × Holsteins tended to have better gains, were more feed efficient, and produced carcasses with greater muscling, FT, and better yield. Furthermore, B×HO had a lower cost of gain and greater carcass value, revenue, and breakeven feeder calf cost compared with their HO contemporaries.

Le dedico esta tesis a mis padres – mami, papi, y mamá. Sin su trabajo y esfuerzo, esto no hubiese sido posible. Los amo.

I dedicate this thesis to my parents – mami, papi, y mamá. Without their hard work and support, none of this would have been possible. I love you.

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LIST OF ABBREVIATIONS

ADG	Average daily gain
AMS	Agricultural Marketing Service
AN	Angus
B×HO	Beef × Holstein
BB	Belgian Blue
BD	Blonde d'Aquitane
BR	Brahman
BW	Body Weight
cEBF	Carcass empty body fat
CH	Charolais
DM	Dry matter
DMI	Dry matter intake
EBF	Empty body fat
F	Friesian
FDA	Food and Drug Administration
FT	Fat thickness
G:F	Gain-to-feed ratio
GV	Gelbvieh
HCW	Hot carcass weight
HF	Hereford
HH	Horned Hereford
HO	Holstein

HOF	Holstein-Friesian
IMF	Intramuscular fat
JE	Jersey
KB	Wagyu
KPH	Kidney, pelvic, and heart fat
LM	Limousin
LMA	Longissimus muscle area
LMAN	Limousin × Angus
MA	Maine-Anjou
pEBF	Predicted empty body fat
pEBW	Predicted empty body weight
pHCW	Predicted hot carcass weight
PI	Piedmontese
pSBW	Predicted shrunk body weight
QG	Quality Grade
REA	Ribeye area
SB	Brown Swiss
SBW	Shrunk body weight
SM	Simmental
SMAN	Simmental × Angus
SR	Swedish Red
U.S.	United States
USDA	United States Department of Agriculture

YG	Yield Grade

CHAPTER 1: LITERATURE REVIEW

Introduction

When discussing beef × dairy breed types, it is important to highlight the differences between beef and dairy breeds of cattle. Dairy cattle have been intensively selected for greater milk yields, while beef cattle have been intensively selected for a greater retail yield of their lean. These two production systems resulted in two different breed types, with dairy cattle having a less muscled, angular conformation when compared with beef cattle. However, even though Holsteins (HO) are a dairy breed, they are a significant source of beef for the U.S. beef supply. Holsteins provide a substantial portion of the industry's fed calf supply as heifers that do not meet dairy industry standards for replacement heifers, and surplus bull calves (Peters, 2014). Historically, these bull calves have been a profitable by-product of the dairy industry (Stiles, 1971; Peters, 2014) and are big contributors to the beef industry, representing 20 to 23% of the beef produced in the U.S. (DelCurto et al., 2017). However, dairy steers incur more carcass discounts when compared with their beef counterparts (Ledbetter, 2018). Furthermore, dairy steers have a less desirable feed conversion, have poorer health, lesser dressing percentages, and lighter muscled carcasses compared with beef steers (Grant et al., 1993). Holsteins are often discounted when compared with beef breeds due to their lower anticipated yield, greater frame size, and greater liver abscess incidence (Dhuyvetter, 1995; Duff and McMurphy, 2007). The decision of a major beef packer to not accept fed HO steers for slaughter substantially decreased the value of HO steers when compared with beef-type cattle (McKendree et al., 2021). This decision led to a reduction in market competition for dairy-type cattle, creating a market barrier for fed HO (McKendree et al., 2021).

Crossbreeding is a generally recommended and accepted beef production practice (Long, 1980) that has been traditionally used in beef cattle to improve performance and adaptability of genetic resources (Gregory and Cundiff, 1980) by combining desirable traits from different breeds (Cartwright, 1970; Rezagholivand et al., 2021). Breeding dairy dams to beef sires allows greater quality beef to be produced from the resulting beef × dairy crossbred offspring (Ettema et al., 2017; Rezagholivand et al., 2021). Since 2017, there has been a considerable increase in the use of beef sires on low genetic merit dairy dams in the U.S. to increase calf value and overall economic return for dairy producers (Bohnert, 2023). Beef × HO crossbred offspring may benefit from heterosis, but the literature suggests this may depend greatly on sire breed selection. Additionally, increasing volatility in milk prices has led dairy producers to practice other ways to generate cash flow. Beef × dairy calves may generate more revenue than dairy-sired calves, creating a strategy to increase the value of calves produced by dairies. Beef × dairy calves have been reported to have greater average daily gain (ADG), dry matter intake (DMI) and improved feed efficiency compared with their dairy counterparts (Basiel and Felix, 2022). Additionally, data suggest that beef × dairy cattle outperform their dairy counterparts in carcass weight and dressing percentage; however, there is variability regarding ribeye area (REA) (Basiel and Felix, 2022). Net value of beef × dairy cattle is ultimately determined by feedlot performance and carcass traits, as they contribute most to overall costs and value of the finished product.

Beef production systems in the United States and Europe

The current literature regarding beef × dairy crossbred cattle is predominantly based outside of the U.S., in European countries. The literature from the U.S. is mostly dated and not aligned with current production standards and breed genetics. Therefore, it is important to denote the similarities, but most importantly the differences in the U.S. and European beef industries. The U.S. and Europe rank among the top five largest producers of beef in the world (Normile et al., 2004), with both having diverse and vastly different production systems. Beef production in the U.S. and Europe are characterized by diverse climate and environmental conditions, animal phenotypes, production intensities, and management and nutritional practices (Drouillard, 2018; Hocquette et al., 2018). These characteristics affecting the U.S. and European beef production systems result in genetic variability among breeds, as well as different beef breeds being used by both countries. The most common beef breeds in Europe are those mainly of continental genetics such as Blonde d'Aquitane (BD), Charolais (CH), Chianina, Gelbvieh (GV), Limousin (LM), Maine-Anjou (MA), Normande, Piedmontese (PI), and Simmental (SM) (Thomas, 2009; Young, 2018). These breeds are generally large-framed and produce lean meat with great yield (Young, 2018). Similarly, some of the most common breeds used in the U.S. beef industry are of continental descent: SM, LM, and CH (Young, 2018). Furthermore, the rest of the most common U.S. beef breeds according to Drouillard (2018) are Angus (AN), Hereford (HF), GV, Brangus, Beefmaster, Shorthorn, and Brahman (BR). Continental genetics of European breeds have long been used in the U.S. as they yield greater dressing percentages, muscling, and less fat, the latter being a preference of European consumers (Long, 1980). Additionally, these continental breeds were introduced in the U.S. to be crossed with British-influenced cattle to improve frame and muscling (Drouillard, 2018; Young, 2018). While continental genetics have historically helped improve growth rates and profitability in the U.S., the U.S. beef industry is driven predominantly by British genetics with the AN breed influencing the vast majority of fed cattle in the country (Drouillard, 2018; Young, 2018). It is important to distinguish that dairy cattle, such as the Holstein-Friesian (HOF) and HO breeds, make up a substantial portion of both the European and U.S. beef industries, respectively, as they are a major by-product of the dairy industry (Drouillard, 2018).

The European beef industry caters to food security, sustainable land use, and the consumer, relying on pasture-based rearing systems (Hocquette et al., 2018). Similarly, the U.S. beef industry is predominantly pasture-based, however cattle are usually, but not exclusively, finished in feedlots with high-concentrate diets (Drouillard, 2018). In addition, the U.S. beef industry relies heavily on technologies that enhance or improve reproduction, genetics, growth, and health (Drouillard, 2018), with approximately 95% of U.S. cattle being implanted with growth promoting hormones (Kuchler et al., 1988; NAHMS, 2013). In contrast, the European beef industry is generally against these management technologies due to consumer demand (Hocquette et al., 2018), leading to bans on domestic use of hormonal treatments in 1985 (Lusk et al., 2003) and imported meat derived from animals that received any type of hormonal treatment in 1989 (Tonsor et al., 2005). European consumers have expressed concerns that growth promoting hormones make their food unsafe due to the possibility of residues, even though the U.S. Food and Drug Administration (FDA), USDA, World Trade Organization, and the European Lamming group have reported growth hormones are safe when used responsibly (Lusk et al., 2003).

Per capita beef consumption has been declining in developed countries over the last 20 yrs., most specifically around 12% in Europe and 19% in the U.S. (Farmer and Farrell, 2018). It has been suggested that the use of growth enhancing technologies (Hocquette et al., 2018) and selection for fatness over leanness (Drouillard, 2018) have contributed to this decline in beef consumption in the U.S. In Europe, this rapid decline is challenged further by the heterogeneity in terms of breed distribution across the European continent (Hocquette et al., 2018). These findings show the similarities, but most importantly the differences between the U.S. and

European beef industries and how data may vary among U.S. and European reports of the production of beef × dairy crossbred animals and resulting beef.

Feedlot performance

Nutrient requirements

According to the Nutrient Requirements of Beef Cattle (NASEM, 2016) the nutrient requirements of different cattle breeds are variable. With the exception of maintenance requirements and frame size, there are no adjustments to improve the prediction of nutrient requirements for growing or finishing HO compared with beef cattle (Rayburn and Fox, 1990). Maintenance energy requirements are estimated to be 15% greater for dairy breeds compared with beef breeds (Garett, 1971). Different energy requirements may be reflected as differences in body composition and internal organ size between dairy and beef breeds (Rezagholivand et al., 2021). This may be a result of dairy breeds having large, metabolically active visceral fat depots, which are typically larger than those of beef breeds (Dolezal et al., 1993; Bown et al., 2016). Research regarding differences in nutrient requirements of HO and beef × dairy cattle are lacking, however, it would be expected for the crossbreds to have less energy requirements than their straightbred dairy steer contemporaries.

Growth performance

It has been reported that HO have lower ADG than beef breeds (Duff and McMurphy, 2007), suggesting beef × dairy crossbreds may have improved performance traits compared with HO. Similarly, Rezagholivand et al. (2021), observed that beef × HO crossbred steers, that were fed for an 11-month period, sired by AN, CH, LM, and INRA 95 (a composite breed of CH, LM, BD, MA, PI and Belgian Blue (BB) breeds) had 7 to 10% greater ADG than straightbred HO steers. Several studies have found a significant difference in ADG between beef × HO steers sired by CH, AN, INRA 95 and LM bulls and straightbred HO, agreeing with previous findings that growth performance and feed efficiency of beef × dairy crossbreds is superior to that of HO (Bech Andersen et al., 1977; Forrest, 1977; Long, 1980; Hardy and Fisher, 1996; Barton et al., 2006). In contrast, no differences in ADG were observed between straightbred HO and beef × HO steers sired by continental breeds such as CH, LM and SM in several studies by Forrest (1977, 1980, 1981). No difference between the breed types may have been a result of nutritional constraints as the concentrate portion of the diet was offered at a restricted level.

Beef × dairy crosses have been observed to outperform straightbred dairy breeds (Berry, 2021). Additionally, beef × dairy crossbreds from late-maturing beef breeds have been observed to have superior performance than dairy animals, but data suggests early maturing beef breeds may have comparatively smaller advantages in performance (Berry, 2021). Studies that have investigated the growth potential of different beef cattle breeds reveal the CH breed is characterized by having the greatest ADG while HF had the smallest ADG (Albertí et al., 2008; Pesonen et al., 2013), with Fahmy and Lalande (1975) observing that CH × HO steers had a 14% greater ADG on average than HF × HO steers.

Purwin et al. (2016) studied the effects of sire-breed on the performance of beef × Polish HOF steers sired by HF, LM, and CH bulls. Findings from this study suggested sire breed did not have an impact on the growth rate of the steers sired by LM and CH bulls (Purwin et al., 2016). However, HF-sired crossbred steers had numerically greater ADG and carcass weight gains, while LM × Polish HOF steers had a lesser ADG observed. (Purwin et al., 2016). The HF × Polish HOF crossbred steers having the greatest growth performance suggests the HF breed is adaptable to different fattening systems and can achieve greater weight gains when fed high concentrate diets under intensive feeding systems. Furthermore, the authors reported ADG from both continental breed crossbred steers were unsatisfactory, however, as late maturing breeds, they may not have reached their full genetic potential. Recent work by Jaborek et al. (2019b) suggests that AN-sired steers out of JE dams may have the most beneficial genetics for beef × JE systems in a study that included AN, SimAngus (SMAN) and Red Wagyu (KB) sired steers, as well as straightbred JE steers. Beef × JE steers gained 0.12 to 0.23 kg/d more than JE steers.

Dairy breeds have been extensively selected for greater milk production, which has a positive genetic correlation with a larger frame size (Bohlouli et al., 2015; Xue et al., 2022). In addition, greater milk production has been correlated to more angular animals with less subcutaneous fat (Berry et al., 2004), total carcass fat, and poorer carcass conformation (McGee et al., 2005; Berry, 2021). In Europe, carcass conformation is scored based on the EUROP classification system that grades conformation in six categories, where S = superior, E = excellent, U = very good, R = good, O = fair, and P = poor (Piedrafita et al., 2003). In comparison, beef × dairy crossbreds tend to be smaller framed (Vestergaard et al., 2019) than straightbred dairy cattle. Hessle et al. (2019) found the difference in traits of CH × Swedish Red (SR) and CH × Swedish HO crossbred steers, when compared with their dairy breed counterparts, were only revealed after harvest. This suggests that when evaluating differences between beef × dairy crosses and straightbred dairy steers in the feedlot, liveweight gain alone is not sufficient, and carcass characteristics after harvest are important in determining their overall value.

Growth performance of beef × dairy cattle appear to be superior to that of straightbred dairy cattle. When compared with their straightbred dairy contemporaries, beef × dairy steers demonstrate greater average daily gain and improved feed efficiency. Overall, the studies on growth performance in beef × dairy steers suggest that this crossbreeding production system may be an effective approach for enhancing growth rates.

Dry matter intake

When compared with beef breeds, HO steers have a greater DMI (Dean et al., 1976; Wyatt et al., 1977; Crickenberger et al., 1978; Harpster et al., 1978; Thonney et al., 1981; Plegge et al., 1984). In a study by Hicks et al. (1990), DMI was observed to be 8 to 15% greater for HO steers when compared with beef steers. Similarly, previous studies reported that DMI of HO steers compared with beef steers was between 8.2 and 13% greater as well (Plegge et al., 1984; Owens et al., 1985; Thonney, 1987; Zinn, 1987). Several studies have compared DMI between dairy and beef × dairy cattle (McGee et al., 2005; Clarke et al., 2009; Keane, 2010; Hessle et al., 2019; Jaborek et al., 2019b). A study by Akbaş et al. (2006) found no significant differences among LM, LM × Friesian (F), and PI × F cattle. In contrast, HF and LM steers had a greater corn silage DMI compared with purebred HOF steers (Huuskonen et al., 2008).

There were no differences observed in a study that compared grass silage DMI of HOF and CH × HOF cattle (McGee et al., 2005). In agreement, Hessle et al. (2019) observed that CH × Swedish Red (SR) and CH × Swedish HO steers had similar DMI when compared with purebred SR and Swedish HO steers. In contrast, one study showed that residual feed intake was superior in beef steers when compared with dairy steers, due to the beef steer's faster growth rates (Clarke et al., 2009). When compared with beef and beef × dairy steers, HO steers have a lesser ADG and typically remain on feed longer, resulting in greater feed consumption and heavier finished weights (Duff and McMurphy, 2007; Pfuhl et al., 2007; Vestergaard et al., 2019; Rezagholivand et al., 2021). Therefore, it would be expected for beef × dairy crosses to be intermediate between their respective component breeds.

A study by Rezagholivand et al. (2021) reported that CH × HO crossbreds consumed 8% less DM/kg weight gain when compared with straightbred HO calves, while Pfuhl et al. (2007) reported CH × HO crosses consumed 13.6% less energy per kg weight gain when compared with

HO calves. Similarly, while not different throughout the growing phase, Keane (2010) reported HOF had a greater DMI during the finishing period when compared with AN × HOF and Belgian Blue (BB) × HOF steers. Jaborek et al. (2019b) reported greater ADG in beef × JE steers sired by KB, AN, and SMAN bulls when compared with straightbred JE steers, potentially reflecting less daily DMI by straightbred JE steers. Furthermore, in the same study, AN × JE steers consumed 14% more DM/d and spent 34 less d on feed than KB × JE steers, while KB × JE steers spent 24 more d on feed than SMAN × JE to achieve the desired harvest endpoint. Overall, DMI is variable across studies, which may be due to different effects such as environment, feeding system, frame size, nutrient requirements, and sire breed influence.

Feed efficiency

Purwin et al. (2016) reported CH × Polish HOF, HF × Polish HOF and LM × Polish HOF crossbred steers were all characterized by similar feed efficiencies. In addition, DMI/kg of carcass weight in HF × Polish HOF steers was comparable to that of straightbred HF steers, but was 20% greater in CH × Polish HOF steers. Studies by Jaborek et al. (2019a) observed that feed conversion did not differ between KB × JE, AN × JE, and SMAN × JE steers and heifers.

Fahmy and Lalande (1975) observed that CH × Swedish HO steers were 8% more efficient at converting feed to gain than HF × HO steers. Similarly, Rezagholivand et al. (2021) observed CH × HO calves were 9 to 13% more efficient in converting feed to gain than beef × HO crossbred steers sired by AN, LM, and INRA 95, or purebred HO steers. Furthermore, Hessle et al. (2019) reported that feed efficiency in CH × SR and CH x Swedish HO steers was superior to that of straightbred dairy steers.

It would be expected for beef × dairy crossbreds to be between their beef and dairy counterparts in terms of feed efficiency. While there is little recent data comparing feed efficiency between dairy and beef × dairy cattle, variation in observations among studies may be largely attributed to the variation that breed interactions introduce into the crossbreds.

Health

The HO cattle tend to be at greater risk than beef breeds for gut health issues (Grant et al., 1993; McCabe et al., 2022) and may suffer from greater death losses (Duff and McMurphy, 2007). Therefore, the increased interest in beef × dairy systems may be partially attributed to suggestions that beef × dairy crossbreds may have health advantages over dairy breeds. Furthermore, while the effects of crossbreeding systems on health are not completely clear, there have been suggestions of greater disease and parasite resistance among crossbreds (Long, 1980). Haagen et al. (2021) estimated that calf respiratory disease, scours, and survivability to one year of age are lowly heritable traits in dairy calves and suggested that heterosis may impact these traits and give an advantage to beef × dairy crossbreds over dairy calves. However, Arens et al. (2021) observed no variation in respiratory disease or scours between LM × dairy and HO heifers. It should be noted that while health may be improved by genetic selection and heterosis within a beef × dairy system, it may be difficult to express these advantages under good management conditions as suggested by Haagen et al. (2021).

Steckler and Boerman (2019) studied AN × HO crossbreds and HO male and female calves that were being offered milk *ad libitum* for over 60 d and it was observed that healthy AN × HO calves consumed 20 L more milk than healthy HO calves. However, AN × HO crossbred calves with lung lesions consumed 37 L less than HO with similar lesions, which suggests milk intake declined to a greater degree for AN × HO crossbred calves than HO calves when challenged with respiratory disease (Steckler and Boerman, 2019). Höglund et al. (2018) hypothesized crossbred steers (CH × Swedish HO) would be less resistant to gastrointestinal nematodes and have a greater depression in performance compared with conventional beef steers, as it would be expected for beef × dairy calves to have intermediate health to their breed type contemporaries. The crossbreds were infected with gastrointestinal nematodes during their first grazing season and subsequently allowed to graze on infected pastures, leading to infection being more severe in the crossbreds when compared with dairy steers. A greater susceptibility to nematode infection in beef × dairy crossbreds could have been due to genetic differences (Rauw et al., 1998), nutritional constraints (Coop and Kyriazakis, 1999), or variation in feeding behavior (Höglund et al., 2018). These factors may outweigh the possibility of an observable heterosis effect on parasite resistance from crossbreeding beef × dairy cattle (Hessle et al., 2019). Even though parasite resistance was lesser in CH × SR and CH × Swedish HO steers, growth was not greatly suppressed, as weight gain in crossbreds was 50% greater than that of dairy steers (Hessle et al., 2019). While more data is required to understand the overall effect of beef × dairy crossbreeding systems on health, health does not seem to be different between beef × dairy and dairy cattle.

Harvest endpoint

Finding an optimal harvest endpoint is often challenging, especially when comparing breed types that may differ in their optimal harvest endpoint. Age or weight should not be the only determining factors for endpoint because important carcass traits may be influenced by both factors. Live body weight (BW), fat thickness (FT), internal fat, longissimus muscle area (LMA), and marbling are important elements to observe because they are the indicators of yield grade (YG) and quality grade (QG) (Long, 1980), and as a result some of the primary drivers in the overall resulting carcass value. Beef × dairy crossbreds tend to be fatter than dairy animals at a given age (Eriksson et al., 2004; Berry and Ring, 2020), which could be because many crosses are sired by early maturing beef breeds (Berry, 2021).

In many cases, treatments are harvested at a point which they visually appear to have the subcutaneous fat thickness correlated with the desired dressing percentage and QG. In a study by Bertrand et al. (1983), groups of beef, dairy, and beef × dairy crossbred steers, sired by AN, HF, HO, and Brown Swiss (SB) bulls from dams of the same breeds, were sent to harvest when visually reaching an apparent low Choice QG. Live BW and hot carcass weight (HCW) in this study were greater for dairy-type steers when compared with beef-type steers, however all steers sired by AN had greater marbling and QG. The results from the study by Bertrand et al. (1983) suggest that harvesting cattle at apparent similar QG may not be ideal nor equitable as a difference was observed for the AN compared with steers of other breed types. In contrast, a study by Coleman et al. (2016) harvested HH-sired AN, AN × HOF, AN × HOF-JE, and AN × JE steers by two weight blocks to ensure they reached an average of 550 kg of live BW with the average harvest age for each block being 22 and 25 mo. Subcutaneous FT, measured between the 12th and 13th rib, and marbling were similar for all steers at harvest, with dressing percentages being less for AN × HOF-JE and AN × JE steers compared with HH × AN steers.

Carcass ultrasound scanning is a non-invasive way of predicting YG and QG by measuring LMA, rump fat, FT, and intramuscular fat percentage (IMF) (DuPonte and Fergerstrom, 2006). Use of ultrasound in predicting carcass traits in live animals varies among studies, but overall has been demonstrated to be moderately accurate (Perry and Fox, 1997; Hassen et al., 1999; Charagu et al., 2000). Guiroy et al. (2001) developed an equation to predict empty body fat (EBF) from carcass measurements to improve endpoint determination based on body composition rather than simply weight. The empty body fat (EBF) percentage provides an indication of the energy reserves stored as fat in an animal's body and may be used in determining the body composition and nutritional status of the animal (Guiroy et al., 2001).

Different cattle breeds can exhibit variations in their propensity to store fat in the various fat depots, which can influence EBF percentage. Data sets that included 966 steers and heifers from previous studies by Crickenberger (1977), Danner (1978), Harpster (1978), Woody (1978), Lomas (1979) and Perry et al. (1991) were used to validate the equation by Guiroy et al. (2001). Guiroy et al. (2001) used live BW to predict HCW by fitting a series of equations. Live BW was converted to shrunk BW (SBW) with Eq. 1 (NASEM, 2016):

$$SBW = Live\ BW \times 0.96$$

Followed by SBW being converted to empty BW (EBW) using Eq. 2 (NASEM, 2016):

$$EBW = SBW \times 0.891$$

Subsequently, EBW can be used to calculate predicted HCW (pHCW) using Eq. 3 (Garrett and Hinman, 1969):

$$pHCW = (EBW - 30.26)/1.362$$

Predicted EBF (pEBF) can then be computed with FT and LMA obtained from ultrasound scanning, pHCW, and USDA QG with Eq. 4 (Guiroy et al., 2001).

$$pEBF\ \% = 17.76207 + (4.68142 \times FT) + (0.01945 \times pHCW) + (0.81855 \times QG) - (0.06754 \times LMA)$$

where QG is assigned a numerical score. The predicted EBF% can then be used to determine a common harvest composition endpoint for different breeds of cattle.

Carcass characteristics

Dressing percentage

Dressing percentage is calculated by dividing the HCW by the live BW, and can be influenced by many factors such as gut fill, muscle mass, internal organ size, kidney, pelvic, and heart fat (KPH), and overall carcass fatness (Jones et al., 1985). Holsteins are known to have a lesser dressing percentage than beef breeds (Nour et al., 1983; Thonney, 1987). This agrees with studies by Rezagholivand et al. (2021), who found that straightbred HO calves had dressing percentages that were 4 to 6% lesser than CH × HO, INRA 95 × HO, and LM × HO crossbred calves, but similar to that of AN × HO calves. In addition, Purwin et al. (2016) reported LM × Polish HOF steers had the highest dressing percentages when compared with CH × Polish HOF and HF × Polish HOF steers, suggesting sire breed may have an effect on dressing percentage. At equal live BW, dairy cattle typically receive discounted prices due to their lesser dressing percentage compared with that of beef cattle (Foraker et al., 2022b).When compared with their counterparts, the dressing percentage of steers sired by HF bulls from AN, AN × HOF, AN × HOF-JE, and AN × JE cows was greater than dairy steers but lesser than beef steers (Barton et al., 1994; Barton and Pleasants, 1997; Purchas and Morris, 2007; Clarke et al., 2009; Coleman et al., 2016). These reports agree with Forrest (1977), where CH × HO steers had a dressing percentage of 58.8% which was 2.1% greater than HO steers. Forrest (1980) found that SM × HO heifers and steers had a dressing percentage 1% greater than HO steers, and in another study, Forrest (1981) observed a similar trend in LM × HO steers and heifers compared with HO steers. Dressing percentages of SM × HO and LM × HO were 58.6 and 59.4%, respectively, when compared with HO steers that averaged 55.7%. Furthermore, CH × HO and HF × HO steers in a study conducted by Fahmy and Lalande (1975) had dressing percentages that ranged from 55 to 57% when fed to three different target weights of 454, 544, and 635 kg. However, it is relevant to state that the previously mentioned dressing percentages for beef × HO crossbreds are less than what is expected from conventional beef cattle, which typically average near 63% (Basiel and Felix, 2022). Furthermore, greater dressing percentages of beef × JE crossbreds sired by KB (63.2%), AN (64.2%) and SMAN (63.4%) bulls and straightbred JE (61.2%) steers were obtained in a study by Jaborek et al. (2019b).

Coleman et al. (2016) reported that lesser dressing percentages from HF × AN-HOF steers was due to greater non-carcass fat, viscera, and gut contents when compared with HF × AN steers. This stands to reason, because it would be expected that dressing percentages for beef × dairy crosses to be between their beef and dairy counterpart averages (Berry, 2021). In further agreement with these findings, Hessle et al. (2019) found that CH × SR and CH × Swedish HO crossbred steers had greater dressing percentages in comparison to straightbred dairy steers. Dressing percentage between beef × dairy crossbreds suggested that crossbreds from late maturing, continental beef sires, such as CH and SM, had dressing percentages that were on average 2% greater than those of crossbreds sired by early maturing beef breeds (i.e., AN and HF) (Kempster et al., 1982). The USDA National Daily Cattle Beef Summary Report reported the average dressing percentage for beef cattle to be 63% for the month of August, 2022 (U.S.D.A., 2022, 2023) but did not report an average for dairy or beef × dairy cattle. While a high dressing percentage is important, it is recommended to be cautious when selecting to improve this trait because it may be detrimental to gastrointestinal tract capacity and resulting size of the visceral organs (Berry, 2021). Dressing percentage is affected by the percentage of fat and muscling in a steer, as evidenced by McGee et al. (2008) where carcass traits of CH, HO and F steers were observed. In the same study, muscling was observed to be greater for the CH compared with the dairy breeds while the proportion of fat was lesser. Furthermore, dressing percentage was observed to be greater for the CH compared with the HO and F primarily due to the CH having lesser proportions of gut fill, internal organs, and internal fat. These results aligned with previous reports (Keane et al., 1989; McGee et al., 2005), showing the influence and importance of these traits regarding dressing percentage.

Frame size

Larger frame size is a current packer concern, with a major packer excluding dairy cattle, such as HO, due to their larger frame size (McKendree et al., 2021). Furthermore, Baker et al. (1984) reported that the average length of HO carcasses was 134 cm, while HF × HO crosses were 127 cm. In extreme circumstances, carcasses may be long enough to drag on the kill floor in older commercial abattoirs that were not designed to accommodate longer carcasses (Bailey and Felix, 2022). Frame size may also influence the difference in dressing percentage between beef and dairy breeds due to finished HO being longer bodied and taller than their counterparts (Basiel and Felix, 2022). Thus, breeding beef sires, specifically continental genetics, to dairy dams has led to concerns regarding frame size (Bailey and Felix, 2022). However, CH genetics have been observed to mitigate the undesirable frame traits introduced by HO cattle (Fahmy and Lalande, 1975; Rezagholivand et al., 2021). Holsteins have the longest carcasses when compared with beef and beef × dairy crosses, averaging 6% longer than beef animals (Albertí et al., 2008; Berry, 2021). This agrees with reports by Baker et al. (1984) that heterosis for carcass length was less than 2.1% for AN, Brahman, HF, HO, and JE cattle.

The USDA Agriculture Marketing Service Standards for Grades of Feeder Cattle evaluates several traits: skeletal size, body thickness, and health (U.S.D.A., 2000). These standards have failed to keep pace with changing cattle genetics and body types, and therefore, are not helpful in differentiating HO, beef, or their crosses in terms of frame size. For example, in the standards, large frame feeder cattle are those expected to exceed 567 kg when reaching 1.27 cm FT and low-Choice QG. According to live cattle evaluations by the National Beef Quality Audit in 2016 (Boykin et al., 2017), 15% or less of the fed cattle population weigh less than 567 kg of live BW.

Cattle skeletal size may also be evaluated through objective, numerical descriptions such as frame scores (Dhuyvetter, 1995). The Beef Improvement Federation (BIF) recommends a frame scoring system in bulls that estimates skeletal size based on hip height and age (Hammack and Gill, 2001). Following BIF (2023), the frame scoring system is derived with Eq. 5:

$$Frame\ Score = -11.548 + (0.4878 \times Ht) - (0.0289 \times Age) + (0.00001947 \times Age^2) + (0.0000334 \times Ht \times Age);$$

where Ht = hip height in inches, and *Age* = days of age.

Hot carcass weight

Large HCW can potentially lower fixed costs of processing because larger carcasses can yield a greater mass of retail cuts (Judge et al., 2019), while maintaining similar facility and labor requirements. Several studies have demonstrated that carcass conformation is usually superior for beef × dairy cattle when compared with dairy breeds (Eriksson et al., 2004; Hessle et al., 2019; Berry and Ring, 2020; Berry, 2021). This agrees with McGee et al. (2020), who reported that CH × HO carcasses had a greater conformation score than carcasses of HO and F steers.

Heterosis does not appear to have a large effect on carcass weight, and in general, carcasses from beef × dairy steers are lighter than beef, but heavier than dairy steer carcasses (Berry, 2021). In a study by Berry and Ring (2020), mean carcass weights of beef × dairy crossbreds were 8.9 kg heavier than that of dairy steer carcasses. Results from Forrest (1980), reported that SM × HO steers and heifers had carcass weights that were 5% greater than straightbred HO steers. Similarly, Forrest (1981) observed that even though they were slaughtered at an average live BW of 502.5 kg, carcass weights of LM × HO steers and heifers exceeded that of straightbred HO steers by 20 and 18 kg respectively. Furthermore, CH × HO crossbreds had a greater mean carcass weight that exceeded HO carcasses by 27 kg and Friesian (F) carcasses by 41 kg in a study by McGee et al. (2020).

It has been observed that carcass weight between HOF and AN × HOF crosses was similar (Berry, 2021). In agreement, grain-fed CH × HO steers and straightbred HO steers did not show differences in carcass weight (Forrest, 1977). Due to their inferior carcass conformation scores, dairy breeds usually produce lighter primal cut yields. Although, when compared with AN cattle the differences were small or nonexistent (Berry, 2021; Judge et al., 2021). This agrees with results of Huuskonen et al. (2013), where they did not find a difference in primal cut yield between AN × HO and HO bulls, though carcass conformation was greater for AN × HO bulls (Huuskonen et al., 2013; Berry, 2021). Due to the lack of difference in carcass weight and primal cut yield between AN × dairy crosses and HO, it can be implied that the carcass yield differences between these breed types are small (Berry, 2021).

Longissimus muscle area and shape

Longissimus muscle area (LMA) and shape are important factors that affect portion size and cooking attributes. This presents a challenge for rib and loin steaks from dairy cattle because they often have undesirable shapes and angularity (Schaefer, 2005; Steger, 2014). Strip loin and ribeye steaks from straightbred dairy cattle exhibit a more triangular shape and smaller total surface area when compared with beef steaks that are more symmetrical and larger in size (Foraker et al., 2022b). In addition, Hood and Riordan (1973) observed that strip loin steaks from beef × dairy cattle were more similar to that of beef cattle for all steak width measures such as lateral regions most prone to angularity, when compared with steaks from dairy cattle. However, despite the display challenges dairy steaks may present at retail, dairy steaks are often chosen over beef × dairy steaks by restaurants due to more consistent sizes (Foraker et al., 2022b).

Results from Rezagholivand et al. (2021) showed beef × HO crosses such as CH × HO and INRA 95 × HO had a larger LMA than straightbred HO. Wolfová et al. (2007) observed carcass muscling using the EUROP carcass grading-system that examines 6 classes to describe "fleshiness". They found that beef × dairy carcasses were more muscular than straightbred dairy carcasses. Albertí et al. (2008) also found that HOF tend to have smaller LMA and longer longissimus muscles compared with 15 different beef breeds. Forrest (1977, 1980, 1981) observed that the LMA of LM × HO heifers and steers exceeded that of HO steers by 17 and 18 cm^2 respectively. Lucas et al. (2021) also found that LM × HO cattle had greater LMA than LM × JE cattle.

Several studies disagree with the findings stated above, such as Baker et al. (1984), where HF × HO and AN × HO crossbreds did not differ in LMA from straightbred HO in intensive grain-based systems. In addition, when standardized to a common HCW, beef × JE crossbreds sired by AN, SMAN, and KB bulls had similar LMA when compared with straightbred JE steers (Jaborek et al., 2019b). The LMA were larger in size for AN and SMAN sired steers, but this did not ultimately impact YG across the different sire breeds. Similarly, beef × SB cattle sired by AN, HF, and CH bulls presented no significant differences in LMA among the crossbreds (Urick et al., 1974). However, Fahmy and Lalande (1975) observed that when harvested at 635 kg, CH × HO cattle had a LMA that exceeded that of HF × HO cattle by 14 cm^2. Taken together, these findings suggest that compared with their dairy contemporaries, continental breed sires may produce crossbred progeny with greater LMA, and British breed sires may produce crossbred progeny with similar or smaller LMA.

Yield Grade and fat thickness

Traditionally, beef from cull dairy bulls and cows has been a significant source of lean beef for packers in the U.S., however dairy breeds tend to have less red meat yield compared with beef breeds (Moreira et al., 2021). This may be evidenced with research conducted by Lawrence et al. (2010) that compared red meat yield of beef-type and calf-fed HO steer carcasses, where beef-type carcasses had a greater overall yield compared with calf-fed HO carcasses (70.4 vs. 68.2%, respectively). However, it is important to note that the current USDA YG equation may be a poor estimator of red meat yield because it does not take into account measures such as muscle to bone ratio. Lower red meat yield of dairy cattle is considered a major concern for beef processors and serves as one of the primary reasons for packer discounts for dairy animals (Foraker et al., 2022b). Additionally, the relationship between equal saleable carcass tissue and live BW favors beef when compared with dairy cattle. This may be attributed to a lesser muscle-to-bone ratio for dairy carcasses (Jaborek et al., 2023).

Loin muscle area has conventionally been used as an indicator of carcass muscling and yield (Rezagholivand et al., 2021). Hessle et al. (2019) evaluated carcass conformation of CH × SR and CH × Swedish HO and their straightbred dairy counterparts and found that crossbreds had 11.1 kg heavier hindquarters, with greater proportions of lean meat and valuable retail cuts, in comparison to the straightbred dairy cattle. Similarly, a study by Foraker et al. (2022a) demonstrated that at a constant HCW, beef × dairy crossbreds exhibited intermediate LMA size as well as intermediate 12th rib FT when compared with their beef and dairy counterparts. The intermediate position of beef × dairy crossbreds, in terms of muscle and FT, results in a lesser percentage of YG 4 and 5 carcasses when compared with beef steers and a greater proportion of YG 1 and 2 carcasses than dairy steers (Foraker et al., 2022b). The USDA YG is determined subjectively by graders at abattoirs; however, it can also be calculated by an equation that takes into account HCW, LMA, FT measures and an estimate of KPH. The subjective grading method introduces variability and a higher margin of error, as seen in studies by Jaborek et al. (2019a, b) where KPH fat estimated subjectively by a carcass grader averaged 4.60% less than an objective measure. To be able to calculate and predict retail yield more accurately, the USDA YG equation might benefit from adjustments on the currently included measurements as well as including additional variables that may affect the overall yield and resulting value of the carcass.

Fat thickness is a carcass measurement that has the greatest impact on estimating the retail yield, and as such, it is an extremely important measure to observe. Beef × dairy steers in a study by Bertrand et al. (1983) had lesser FT than beef steers and greater 12th rib fat deposition than dairy steers, demonstrating the crossbred steers ability to produce heavier and leaner carcasses as an intermediate between both breed types. In a study by Rezagholivand et al. (2021), FT over the back, loin, front and hindquarter was greater for AN × HO crossbreds compared with straightbred HO. In a study by Jaborek et al. (2019b), AN × JE steer carcasses exceeded straightbred JE steers by 0.51 cm in back FT, while SMAN × JE and KB × JE steers had intermediate backfat thicknesses. Wheeler et al. (2005) reported that AN × HO had greater 12th rib FT than CH and SM cattle. Fahmy and Lalande (1975) observed that HF × HO steers exceeded CH × HO steers in backfat thickness by 0.17, 0.26, and 0.82 cm when harvested at 454, 544, and 635 kg, respectively. Similarly, LimFlex (LMAN) × dairy cattle had 0.08 cm greater FT than LM × dairy cattle (Lucas et al., 2021), which may be a suggestion of sire-breed influence within crossbreds.

In contrast, Hessle et al. (2019) found that CH × SR and CH × Swedish HO crossbred steers had no difference in carcass fatness when compared with straightbred dairy steers. Similarly, in two separate studies, 12th rib FT among carcasses from CH × HO heifers and steers, SM × HO heifers and HO steers was similar (Forrest, 1977, 1980). Furthermore, FT of LM × HO heifers and steers and HO steers were similar between steers (Forrest (1981). While JE influence has not been studied as much as other dairy breeds, they have presented similar trends and tend to have less FT than beef breeds (Basiel and Felix, 2022).

A study by Kenny et al. (2020) did a cross sectional analysis with the EUROP 15-point fat score of more than 4.5 million crossbred cattle, where it was reported that British beef breeds had more fat than other beef breeds, HOF, and JE when adjusted to a common harvest age. Based on a carcass fat score (1 to 5), Keane (2010) also reported more fat cover in HOF (3.44) when compared with BB x HOF steers (2.96), including greater KPH fat weight (8.20 and 6.79 kg, respectively). However, Campion et al. (2009) reported that HO had less fat cover than other dairy breeds and AN × HOF crossbred steers. This is not unexpected, since the HO breed has been aggressively selected for greater milk yields, which leads to lower BCS and subcutaneous fat cover when compared with other dairy breeds (Berry et al., 2003; Berry, 2021).

Overall, carcasses from British influenced cattle had a greater FT compared with those with continental influence and dairy sires. The current body of literature is different across studies and differences in FT may be a result of the age of the studies (in some instances) and most importantly, sire breed genetics.

Marbling and Quality Grade

Dairy cattle have been reported to have greater marbling than their beef counterparts (McKenna et al., 2002; Schaefer, 2005), which regularly results in greater QG. Dairy cattle generally contribute positively to the U.S. QG distribution, with one report estimating they comprise about 32% of the USDA Prime QG (Boykin et al., 2017). Data indicates this positive influence may be retained on beef × dairy crossbreds, as between 35 to 45% of beef × dairy carcasses exhibit modest or greater marbling that meet qualifications for branded beef programs in the U.S. (Foraker et al., 2022b). Comparably, Hessle et al. (2019) found that CH × SR and CH × Swedish HO crossbreds had lesser marbling scores than straightbred dairy steers. According to the 2016-National Beef Quality Audit, the USDA Choice grade has increased to an average of 67.3% and the USDA Select grade has decreased to 32.6% (Boykin et al., 2017), a prevalence that may at least partially be attributed to the increase in the percentage of dairy-type carcasses, 16.3 vs. 9.9% in the 2011-National Beef Quality Audit (Moore et al., 2012).

In a similar manner as dairy influenced cattle, beef sire breeds with British influence have been observed to improve marbling from beef × dairy progeny. Such was the case for AN × JE genetics in Jaborek et al. (2019a, b) studies, where AN × JE steers increased the numeric marbling score when compared with JE, SMAN × JE, and KB × JE steers. Similarly, LMAN × HO and LMAN × JE cattle reached greater marbling scores than LM × HO and LM × JE in another study (Lucas et al., 2021). An important distinction within beef breeds, the AN breed has been shown to produce carcasses with QG that are significantly greater than those of HO (Cole et al., 1963; Cundiff, 1970), and greater marbling scores when compared with HO (Judge et al., 1965; Wellington, 1971; Ziegler et al., 1971; Young et al., 1978; Bertrand et al., 1983; Keane and Drennan, 2009). Dean et al. (1976) studied AN and CH sired steers from HF, HF × HO, and HO dams and reported that all HO progeny, including AN × HO and CH × HO steers had the greatest marbling scores of all treatments observed. In addition, Bertrand et al. (1983) also found significant heterosis for QG (2.1%) and marbling scores (2.1%) in every beef × dairy cross in their study consisting of steers sired by AN, HF, HO, and SB bulls used on dams of these same breeds. These findings suggest AN and HO genetics may be beneficial for greater IMF deposition in beef x dairy crossbreds.

Tenderness

A major factor in the determination of palatability by consumers is tenderness. Warner-Bratzler Shear Force (WBSF) is a popular method to measure meat tenderness (Wheeler et al., 1997). Shear force evaluation of beef from HF × SB, AN × SB, and CH × SB finished on concentrate-based diets detected no differences in tenderness (Urick et al., 1974). Results from Muir et al. (2000) agree, where they found that beef from HO steers was similar in tenderness to HF and HF × HO steers when processed at the same level of maturity (610 kg) and FT (0.68 cm). Pfuhl et al. (2007) did not detect any differences in beef tenderness of the strip loin when comparing CH and HO bulls, but found that marbling score and IMF percentage were greater in HO. However, Bureš and Bartoň (2018) described beef from AN animals as being more tender, juicy, and flavorful than HO beef. Additionally, O'Ferrall et al. (1989) found no difference in WBSF between F and CH sired steers. This could possibly mean that beef from beef × HO crossbreds sired by HF and CH may be similar in tenderness to that of their HO counterparts.

Recent studies with modern genetics and different feeding systems have allowed researchers to determine eating quality and tenderness differences between beef × dairy and dairy cattle. Cattle evaluated in these modern systems have indicated that beef from SMAN × JE (2.48 kg) and KB × JE (2.39 kg) was more tender than beef from AN × JE (2.76 kg) and straightbred JE (2.71 kg) steers when evaluated from ribeye steaks (Jaborek et al., 2019b). An improvement in tenderness from beef × dairy crossbreds could be influenced by sire breed. However, the differences in Jaborek et al. (2019a) averaged less than 0.5 kg of force, which is unlikely to be detectable by consumers (Destefanis et al., 2008). Similar results from a consumer taste panel resulted in steaks from beef × dairy crossbreds ranking intermediate for tenderness when compared with dairy (lesser) and beef (greater), but overall consumer acceptance was not different among breed types (Foraker et al., 2022b).

Several studies have reported moderately negative associations between sensory scores and WBSF measures of tenderness (Caine et al., 2003; Keady et al., 2017; McGee et al., 2020), which may be a suggestion that WBSF is not a reliable indicator of tenderness from the consumer perspective as consumers may not be consistent in their ability to differentiate between different tenderness levels. However, trained panelists distinguished strip loin steaks from dairy and beef × dairy cattle as more tender than those from beef cattle, while WBSF values for beef × dairy steaks were intermediate and those from beef cattle had the greatest WBSF value (McGee et al., 2020). There seems to be much variation in the literature regarding tenderness and consumer acceptability, suggesting that contrasts between reports may reflect age and IMF differences, as well as other possible influences such as genetic variation across breeds.

Lean color

Steaks from HO cattle receive discounts at retail because of less desirable color more often than those of beef steers (Schaefer, 2005). This can be partially explained by a greater portion of oxidative muscle fibers being exhibited in the longissimus muscle of dairy cattle when compared with beef cattle, which contributes to darker colored steaks overall from the first day of display, as well as faster discoloration rates for dairy cattle muscle (Picard and Gagaoua, 2020). Additionally, Muir et al. (2000) found IMF and water concentrations can lead to differences in lean meat color across breeds. Retailers may be concerned with dairy-influenced beef products due to challenges with color stability in retail display (Picard and Gagaoua, 2020). This is evident, as it has been observed that steaks from straightbred dairy cattle are not merchandised as effectively as those from beef cattle (Foraker et al., 2022b). However, two separate studies by Hood and Riordan (1973) identified that retail color display in beef × dairy crossbred cattle was not concerning when compared with straightbred dairy cattle. It was observed that while inside round and knuckle steaks from dairy cattle reached a level of 20% surface area of discoloration, considered undesirable by consumers at 60 hr of retail display, steaks from beef and beef × dairy steers were not different from each other in color stability and did not reach a level of 20% discoloration until displayed for 84 hr (Hood and Riordan, 1973).

This suggests that meat from beef × dairy cattle may have a greater shelf life than dairy-beef before discoloration makes the product undesirable and less likely to be purchased by consumers.

Consumers may perceive yellow fat as tainted, leading to fewer purchases and a negative view of beef (Dunne et al., 2009; Coleman et al., 2016). Dairy and beef × dairy crossbred cattle have been associated with having yellow fat (Burke et al., 1998; Muir et al., 2000; Purchas and Morris, 2007; Coleman et al., 2016). A study by Muir et al. (2000) compared ribeye steaks from beef, dairy, and beef × dairy steers harvested at the same weight or age. Results from Muir et al. (2000) showed no difference in meat color, but fat from dairy steers was more yellow than that of beef and beef × dairy steers. Jersey cattle have fat that is more yellow in color than that of beef breeds such as AN (Pitchford et al., 2002; Berry, 2021). It is important to note that yellow fat is caused by β-carotene, which when in excess, is stored in fat, resulting in a yellow color (Berry, 2021). In the U.S. beef cattle are usually finished with low forage, high concentrate diets that are relatively low in β-carotene which results in whiter fat. As a result, cattle fed a high forage diet may require more days on a high grain diet to reduce the amount of yellow (Kruk et al., 1998). Results from a study by Strachan et al. (1993) showed that even after longer days on feed, yellow fat color was still observed. The literature shows that even though diet plays a major role in the deposition of yellow fat, genetics seem to play an important role as β-carotene is deposited at different rates across breeds.

Economics of feedlot finishing beef × dairy breed types

According to Dal Zotto et al. (2009) and McHugh et al. (2010), beef × dairy calves have greater value than dairy calves, which generates revenue that can provide extra income for dairy producers. Feedlot operators may benefit from beef × dairy calves as well, because the initial capital cost is lesser relative to beef calves (Berry, 2021). Additionally, less capital may be needed through harvest relative to dairy calves (Berry, 2021) due to less feed consumption and fewer days on feed. Video auction data analyzed by McCabe et al. (2022) reported that beef × dairy steers had a greater relative value compared with HO steers. Furthermore, beef × dairy feeder calves have been reported to be valued at \$100 to \$150 greater than their HO contemporaries (McCabe et al., 2022). Additionally, beef × dairy steers were valued at \$7.92 to \$17.56/45.36 kg of BW less than beef steers (McCabe et al., 2022), which may encourage the continued growth of this production system (Heslip, 2020; Myers, 2020).

Carcass value

Beef × dairy crossbreds may produce a more valuable carcass compared with dairy cattle due to their greater proportion of muscle and more valuable retail cuts (Hessle et al., 2019). Early adoption of beef × dairy crossbreeding systems have focused on producing calves that may capture premiums from branded programs that specify a black-hided phenotype, such as Certified Angus Beef. From 2015 to 2018, the carcass value of dairy cattle decreased substantially, more so with the all-time high discounts on dairy carcasses and the rejection of dairy cattle by a major packer (McKendree et al., 2021).

Holstein fed cattle have traditionally been discounted based on their anticipated lesser retail yield as a result of their lesser muscle to bone ratio compared with beef breeds (Thonney et al., 1991; Steger, 2014). Furthermore, retailers have been found to believe that there is low consumer acceptance of the overall shape and appearance of top loin steaks at retail and claim that beef from HO steers should be discounted (Thonney et al., 1991). To test the validity of such claim, a study conducted by Thonney et al. (1991) allowed retail managers to visually appraise steaks of dairy- and beef-type carcasses. Results from this study showed that they were able to identify the correct breed type only 51% of the time demonstrating the underlying bias of the retailer regarding HO beef.

Liver abscesses are an added concern when crossing beef sires to dairy dams because of the higher incidence observed in dairy-type carcasses compared with beef-type carcasses at the packer (Eastwood et al., 2017). Furthermore, liver abscesses result in slower growth and poorer feed efficiency for dairy-type steers compared with beef breeds, often resulting in losses for the industry (Pinnell and Morley, 2022). The most substantial financial losses related to abscessed livers occur from adhesions of severely diseased livers to high value muscles such as the diaphragm (outside skirt), and these subsequently impact efficiency and cost of production due to contamination of other viscera and carcass tissues from open liver abscesses. This results in the processing line having to do additional trimming and being slowed down (Foraker et al., 2022b). It has been reported that incidence of liver abscesses is greater in straightbred dairy cattle (50 to 80%) when compared with conventional beef cattle (15 to 30%) (Amachawadi and Nagaraja, 2016). Therefore, it would be expected for beef × dairy crossbreds to have greater incidence of liver abscesses than beef cattle and therefore, these discounts may be justified. Data collected from several feedlots by Foraker et al. (2022b) reported that beef × dairy crossbreds exhibited an intermediate abscess rate compared with their counterparts that ranged from 40 to 60%, although wide variations between feedlots was observed. Furthermore, it is not well understood why liver abscesses are more prevalent in dairy than beef cattle (Amachawadi and Nagaraja, 2016), but it has been generally accepted that feeding high concentrate diets for extended periods, which is more common in dairy cattle production systems, increases the chances of rumen acidosis resulting in the development of liver abscesses (Rezac et al., 2014). However, liver abscesses occur in just 10% or less of straightbred dairy cattle fed high concentrate diets in the southwestern U.S., which suggests that sire breed may not be the primary driving influence of this phenomenon in dairy cattle (Reinhardt and Hubbert, 2015; Amachawadi and Nagaraja, 2016).

Summary

Beef × dairy crossbreds seemingly perform better than straightbred dairy breeds when it comes to growth performance, feed efficiency, and many carcass traits. However, the relevant literature is not consistent regarding performance and carcass differences, which is likely the result of different breed and sire effects, as well as production systems. The U.S. and European beef industries are vastly different, meaning that beef × dairy data from Europe may not be an accurate description of the industry in the U.S. Additionally, much of the beef × dairy literature research was conducted 40 or more years ago, during which time production practices and cattle genetics have changed. Regardless of the benefits and growing popularity of beef × HO crossbreds, a market barrier has emerged due to a value disconnect among dairies, calf raisers, feedlots, and beef processors. If value is not determined and retained, the production system could end. Furthermore, it is important to provide research results based in the U.S., to provide more relatable data to researchers and producers. To meet the needs and expectations of both the beef and dairy industries, intentional selection criteria should be used when selecting beef sires for dairy dams. However, selection criteria for crossbreeding scenarios remain poorly defined. As an emerging sector of the industry, future breeding goals should be directed towards raising beef × dairy cattle that improve upon those found in the current supply chain. Therefore, our objective was to determine feedlot growth performance, carcass characteristics, and feeder calf value of beef × HO and HO steers.

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CHAPTER 2: GROWTH PERFORMANCE, CARCASS TRAITS, AND FEEDER CALF VALUE OF BEEF × HOLSTEIN AND HOLSTEIN FEEDLOT STEERS

Abstract

Objective: The objectives of this study were to compare feedlot performance, carcass traits, and value of beef × Holstein (**B×HO**) and Holstein (**HO**) feedlot steers.

Materials and Methods: After a 21-d acclimation to the feedlot, steers (B×HO, n = 60 and HO, n = 60) were blocked by weight into 10 pens per breed type. Steer weight gain, dry matter intake (**DMI**), and gain-to-feed (**G:F**) were measured on a 28-d basis. Steers were harvested at a commercial abattoir on d 245 for B×HO and 266 for HO, after reaching an average predicted empty body fat of 30.7%. Following a 48-h chill, carcass data were collected.

Results and Discussion: The B×HO steers tended to have 5% greater average daily gain (**ADG**) (1.75 vs. 1.70 kg/d; $P = 0.07$) compared with the HO steers, but similar DMI (10.40 vs. 10.35 kg/d; $P = 0.79$). The B×HO steers had 4% greater G:F compared with HO steers (0.172 vs. 0.165; $P = 0.03$). Cost of gain was 14% less for B×HO compared with HO steers ($2.64 vs. $2.81/kg; $P = 0.01$). Although final live weight tended to be less for B×HO compared with HO steers (621.3 vs. 634.8 kg; $P = 0.08$), carcass weights were similar between breed types (365.4 vs. 366.6 kg; $P = 0.78$). The B×HO steers had 20% greater longissimus muscle (**LM**) area (87.8 vs. 73.1 cm^2; $P < 0.0001$), greater backfat thickness (1.18 vs. 0.79 cm; $P < 0.01$), and a lesser average USDA Yield Grade (2.9 vs. 3.2; $P = 0.02$) than HO steers. The B×HO and HO steers had similar average marbling scores (426 vs. 437; $P = 0.62$) and USDA Quality Grade ($P = 0.40$). Based on abattoir prices, carcass revenue tended to be greater for B×HO steers ($1,836/carcass) when compared with HO steers ($1,800/carcass; $P < 0.05$). Calculated breakeven feeder calf value was greater for B×HO compared with HO steers ($368.46 vs. $305.02/100 kg; $P < 0.05$).

Implications and Applications: Overall, B×HO steers were more feed efficient and produced carcasses with more desirable carcass yield, resulting in greater feeder calf value when compared with HO steers.

Key words: beef on dairy, crossbred, breakeven, feedlot

Lay Summary

Beef × dairy crossbred steers may provide an opportunity to improve existing HO steer systems in terms of muscling and may qualify for premiums from branded beef programs such as Certified Angus Beef. As a partial result, beef × dairy production systems have been gaining popularity. The present study evaluated and compared finishing performance, carcass characteristics, and the subsequent value of B×HO and HO steers. Although health was similar, the B×HO steers tended to have a greater ADG and a greater G:F than their HO contemporaries. While it took the HO steers an additional 21 days on feed to reach their harvest endpoint, there were no differences in total average daily DMI between the breed types. Dressing percentage of B×HO steers was numerically greater than that of HO steers, and B×HO carcasses had larger ribeye area and greater backfat thickness than HO carcasses. This resulted in a more desirable USDA Yield Grade (**YG**) for the B×HO carcasses. There was no significant difference in USDA Quality Grade (**QG**) compared with HO carcasses. The improved performance and carcass traits of the B×HO steers resulted in greater carcass value, gross revenue, and breakeven feeder calf value compared with their HO contemporaries.

Introduction

Holstein (**HO**) cattle are a dairy breed that represents approximately 23% of the U.S. fed beef supply (Berry, 2021) from cull cows, and surplus heifer and bull calves. Dairy-type cattle, especially HO steers, typically receive premium Quality Grades (**QG**) and provide a year-round supply of beef (Basiel and Felix, 2022). However, dairy-type cattle can have a lesser gain-to-feed (**G:F**), lesser muscling, and a lesser dressing percentage compared with beef-type cattle (Jaborek et al., 2023). Compared with beef-type steers, dairy-type carcasses receive greater discounts due to their lesser red meat yield, and the decision of a major U.S. packer to stop buying HO fed steers further decreased their value (McKendree et al., 2021).

Recently, the use of beef sires to breed dairy dams with low genetic merit for milk production has increased substantially in the U.S. to increase calf value and overall economic return. From 2017 to 2023, U.S. beef semen sales increased by nearly 6.5 million units, while HO semen sales decreased by around 6.3 million units (NAAB, 2023). These data support the observation that increased beef semen sales are largely attributed to the greater use of beef sires to breed HO females.

Beef × dairy production systems may offer improved feedlot performance and carcass traits for non-replacement heifer offspring compared with straightbred HO systems. In a review of beef × dairy systems, Basiel and Felix (2022) reported that when compared with HO steers, beef × dairy steers had a greater average daily gain (**ADG**), greater dry matter intake (**DMI**), and improved feed efficiency, as well as greater hot carcass weight (**HCW**), dressing percentage, and fat thickness (**FT**). However, available data regarding beef × dairy cattle are primarily based outside of North America, are more than 40 years old, and are not aligned with current production systems and breed genetics.

Therefore, the present study was designed to compare a beef × Holstein (**B×HO**) and straightbred HO steer production system and subsequently calculate relative value of feeder calves. We hypothesized that B×HO steers would outperform their HO steer contemporaries in the feedlot and have improved carcass traits. Our aim was to measure health, feedlot growth performance, DMI, feed efficiency, cost of gain, carcass traits, and carcass value of B×HO and HO steer contemporaries within the current supply chain.

Materials and methods

All procedures and husbandry practices involving live cattle were approved by the Michigan State University (**MSU**) Institutional Animal Care and Use Committee (IACUC-PROTO202100151) and followed guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2020).

Management and diet

One-hundred and fifty straightbred HO (n = 75) and B×HO (n = 75) crossbred steers were purchased from one Michigan calf raiser at approximately 4 mo of age and transported to the MSU Beef Cattle Teaching and Research Center, Lansing, MI. After arriving at the feedlot, steers were weighed, ear-tagged, vaccinated against common respiratory diseases (BOVILIS®, Vista® Once SQ, Intervet/Merck Animal Health, Madison, NJ), clostridial infections (BOVILIS®, Vision® 7 Somnus, Intervet/Merck Animal Health), and were treated for internal (safe-guard®, Intervet/Merck Animal Health), external parasites (Ultra saber™, Intervet/Merck Animal Health), and administered a metaphylaxis treatment (Draxxin®, Zoetis, Kalamazoo, MI) before being separated into pens by breed-type. The receiving weight was an average of 171.9 ± 18.1 kg across breed types. After a 21-d acclimation period (d 0), 60 steers of each breed type that appeared healthy and with a good appetite were blocked by body weight (**BW**) and allotted to one of ten sawdust bedded pens (4.3 x 11.6 m) that contained six steers each in a covered barn. On d 0, steers also received their second administration of vaccines (BOVILIS®, Vista® Once SQ, Vision® 7 Somnus, Intervet/Merck Animal Health).

Every morning prior to feeding, health was monitored for signs of morbidity with criteria based on the DART system as described by Step et al. (2008). If morbid, severity of illness was scored based on depression, appetite, respiratory signs, and movement. Morbid steers were removed from their respective pen for observation and antimicrobial therapy was administered when rectal temperature was ≥ 39.7°C (Draxxin, Zoetis) and a second treatment (Nuflor, Intervet/Merck Animal Health), was administered 48 h later if fever persisted. After treatment, steers were allocated to a hospital pen and were then returned to their home pen after 48 h if no signs of fever persisted.

All steers received a common starter diet that mimicked the diet offered at the calf grower which consisted of whole-shelled corn, oats, pelleted supplement with monensin, molasses, and chopped hay from d -21 to d 21. Steers were then gradually transitioned to a common finishing diet from d 21 to d 49 (Table 1). Steers were fed once daily in the morning (07:00 h) with feed delivery adjustments made to achieve ad libitum intake. Samples of each dietary ingredient were collected every 28 d for nutrient composition analysis (Dairy One, Ithaca, NY). Every 14 d feed ingredient samples were dried for 24 h in a forced air oven at 100 °C to determine feed DM and adjust the ingredient DM percentages accordingly. Feed bunks were cleaned, and refusals were collected and weighed every 14 d. Feed DM disappearance was calculated on a pen basis.

Initial and final BW were the average of weights taken on two consecutive days and steers were weighed every 28 d throughout the trial. The ADG was calculated for every 28-d period as well as from d 0 to finish. The G:F was calculated as ADG divided by average daily feed DMI for the respective period. Steers were implanted with Ralgro (36 mg zeranol; Intervet/Merck Animal Health) on d 56 and Revalor-IS (80 mg trenbolone acetate and 16 mg estradiol; Intervet/Merck Animal Health) on d 140. On d 168, 0.5 mL blood samples were collected on cards and submitted for genotyping with an experimental INHERIT Select evaluation (Zoetis Genetics, Kalamazoo, MI) to determine breed composition. Final hip height was measured the day before harvest, and frame scores were calculated by using an equation for bulls (BIF, 2023), where age at purchase was estimated to be the same for all steers.

Empty body fat (**EBF**) percentage provides an indication of the energy reserves stored as fat in an animal's body and may be used in determining body composition and nutritional status (Guiroy et al., 2001). Different cattle breeds may exhibit variations in their propensity to store fat in the various fat depots, which can influence EBF percentage. Steers used for this experiment represented distinct biological types (HO and B×HO), therefore, typical harvest endpoints such as a common back FT, final live weight, or days on feed may not provide an equitable for this comparison. To compare breed types at an equitable harvest endpoint, a common body composition was determined. Subcutaneous FT measured between the 12th and 13th ribs, longissimus muscle area (**LMA**), and intramuscular fat percentage (**IMF**) were measured by real-time ultrasound (500 V Aloka with 3.5-MHz transducer, Wallingford, CT) on d 196 and d 217 by an Ultrasound Guidelines Council certified technician. The live BW at ultrasound was used to estimate predicted hot carcass weight (**pHCW**) by fitting the following equations for predicted shrunk body weight (**pSBW;**(NASEM, 2016), predicted empty body weight (**pEBW;**(NASEM, 2016), and **pHCW** (Garrett and Hinman, 1969):

$pSBW = live\ BW \times 0.96$ (Eq. 1);

$$pEBW = SBW \times 0.891 \text{ (Eq. 2);}$$

$$pHCW = (EBW - 30.26)/1.362 \text{ (Eq. 3);}$$

where **EBW** is empty body weight. Predicted EBF (**pEBF**) was estimated using an equation developed for steers by Guiroy et al. (2001):

$$pEBF,\% = 17.76207 + (4.68142 \times FT) + (0.01945 \times pHCW) + (0.81855 \times QG) - (0.06754 \times LMA) \text{ (Eq. 4);}$$

where QG was a numerical score (4 = Select; 5 = Low-Choice). The remaining days on feed to achieve a target of 30% pEBF were calculated assuming each percentage unit increase in pEBF was accompanied by a BW gain of 14.26 kg for B×HO steers (Guiroy et al., 2001) and 15.1 kg for HO steers (Perry and Fox, 1997). Predicted EBF was estimated to be 30.6 and 30.8% for the B×HO and HO steers, when harvested on d 245 and 266, respectively.

Carcass data collection

Carcass data were collected at a commercial abattoir (JBS, Plainwell, MI). The HCW was obtained from the abattoir. Kidney, pelvic, and heart fat percentage was determined by the abattoir based on the difference in HCW before and after kidney, pelvic, and heart fat (**KPH**) removal from the hot carcass as part of the standard dressing procedure. Shrunk BW (**SBW**) was determined by subtracting the average actual shrink for each breed type from the final live BW at the feedlot. Dressing percentage was calculated as the HCW divided by the SBW. Liver abscess severity was assigned a score of 0 if healthy with no abscess, A for those with 1 to 2 small or 2 to 4 well organized abscesses, and A^+ for those with 1 or more large abscesses (McCoy et al., 2017). Lungs were assigned a score of 0 to 100%, in increments of 10%, based on their degree of visually apparent consolidation (Rezac et al., 2014). Liver and lung data were available for the B×HO steers only.

After carcasses were chilled for 48 h, 12^{th} rib FT was measured and tracings of each LM between the 12^{th} and 13^{th} rib were obtained using acetate paper according to the procedures of Naumann (1951) and later measured using a plastic grid to determine LMA. Yield grade was calculated (USDA, 2017) and marbling scores were assigned. Quality grades were assigned based on marbling scores. Skeletal maturity was determined by evaluation of cartilage ossification associated with the sacral, lumbar, and thoracic vertebra and lean maturity determined by evaluation of the color and texture of the exposed LM between the 12^{th} and 13^{th} ribs. The CIE L*a*b* (luminance, L*; redness, a*; yellowness, b*) color space of the right LM was the average of measurements collected in three representative locations across the muscle after being allowed to bloom for a minimum of 30 min. Data were obtained using a Nix Pro 2 Color Sensor (Nix Sensor Ltd., Hamilton, Ontario, CA) with CIELAB values referenced to D50 illuminant and a 2° observer angle. Carcass measurements collected were used to determine calculated EBF percentage (cEBF) by using Eq. 1, 2, 3, and 4.

Cost of gain

To obtain a full accounting of costs incurred by the steers, the pre-trial period was also included for the economic analysis. Total operating costs were calculated by adding feed and non-feed operating costs. Cost of gain per kg was calculated by dividing the total operating costs by total BW gained from delivery to harvest. Purchase cost included feeder calf transportation to the feedlot. Total feed cost was the sum of pre-trial, starter, and finishing diet feed costs and included 4.53% interest as published by the Federal Reserve Bank of Chicago (FRBC, 2023). Non-feed operating costs included preventative care (vaccination, deworming, and metaphylaxis), medication (antibiotic treatments), death loss, implant, yardage (including management, taxes, insurance, interest on facilities, machinery, facility repairs, fuel, oil, utilities, depreciation, and bedding), transportation to harvest, and beef checkoff fee. Yardage was estimated as \$1.00 per steer^{-1} per d^{-1} and reflected a similar cost to that published in a survey for a feedlot feeding HO steers for harvest by Halfman et al. (2015). Interest rate of the cattle purchase cost was set at 4.53% (FRBC, 2023).

Carcass value

In the current fed cattle market, B×HO cattle may be priced as HO (Scenario 1), intermediate (Scenario 2), or beef (Scenario 3) due to the uncertainty of their true value. Therefore, four pricing scenarios were developed using the base carcass prices for beef, B×HO, and HO and the appropriate premiums and discounts to determine representative carcass price ranges. The base carcass price of B×HO was an average of the beef and HO base carcass prices. The beef base carcass price assigned by the abattoir was the same as that reported by United States Department of Agriculture (**USDA**) Agricultural Marketing Service (**AMS**) for the weeks of August 3 and August 22, 2023 (USDA, 2022b). The HO steer base carcass price assigned by the abattoir was \$19.85/100 kg less than the beef base carcass price. Carcass premiums and discounts assigned by the abattoir were similar to the weekly USDA AMS weekly direct slaughter cattle premiums and discounts report (USDA, 2022a). The fourth pricing scenario used the beef base carcass price for those with beef-type conformation and the B×HO base carcass price for those with dairy-type conformation. Base carcass prices for this scenario were assigned after a trained evaluator, that was blinded to breed type, visually assessed tracings of the LM and determined breed conformation based on their shapes. Those with beef-type conformation that also met all other specifications for the Certified Angus Beef program obtained a premium of \$9.45/100 kg. Total carcass revenue was the carcass price per 100 kg, after applying premiums and discounts, multiplied by HCW. Breakeven feeder calf purchase value was calculated by subtracting the total cost of gain from total carcass revenue and dividing the remainder by the feeder calf purchase weight.

Statistical analysis

The experimental design was a randomized complete block design with pen serving as the experimental unit. The MIXED procedures of SAS (SAS Inst. Inc., Cary, NC) were used to analyze feedlot performance, DMI, G:F, carcass characteristics, cost of gain, carcass revenue, and breakeven feeder calf value. The FREQ and GLIMMIX procedures of SAS were used to analyze morbidity and mortality percentages and USDA Quality Grade (QG) distribution. Morbidity and mortality were analyzed on an individual animal basis. Carcass pricing scenarios were analyzed on an individual basis with carcass pricing scenarios serving as the experimental units. The statistical model included breed type as a fixed effect, and pen, weight block and random error as random effects. The LSMEANS and PDIFF statements were used to generate least square mean estimates, standard errors, and distinguish differences between breed types. The repeated statement with a compound symmetry covariate was used to analyze feedlot performance. Significance of fixed effects was established at $P \leq 0.05$ and tendencies are discussed at $0.05 < P \leq 0.10$.

Explanation of losses

One B×HO steer died (d 84), one B×HO steer was removed due to chronic morbidity and anorexia (d 84), one B×HO animal was removed after being identified as a heifer (d 140), one B×HO steer was euthanized due to a leg injury (d 243), and one B×HO carcass was unavailable for data collection at the abattoir. One HO steer died after being found inverted in the feed bunk (d 196).

Results and discussion

Breed composition

Even though the crossbred B×HO steers were sourced from the same Michigan calf raiser, the B×HO steers originated from multiple dairies and were likely representative of cattle in the current supply chain. Genomic testing revealed that the beef breed genes of the B×HO steers originated from Angus (**AN**), Limousin (**LM**), LimFlex (**LMAN**), Simmental (**SM**), and SimAngus (**SMAN**) (Table 2). Phenotypically, the B×HO steers were either solid black (57%) or were black with small white markings on their head, legs, and (or) tail (43%). Therefore, all the B×HO steers would have met the hide color specifications for Certified Angus Beef as they were solid black with no other color behind the shoulder, above the flanks, or breaking the midline behind the shoulders, excluding the tail (USDA, 2016). The HO steers also originated from multiple dairies and were verified as straightbred HO (data not shown).

Feedlot performance

Although we observed no differences in BW between the breed types from d 0 to 56, B×HO steers had a greater BW from d 84 to 224 compared with their HO steer contemporaries (Table 3). The HO steers tended (P = 0.06) to have a greater final BW than the B×HO steers, but only because they remained on feed for an additional 21 d to reach the desired market endpoint. While ADG was similar for the breed types throughout most of the feeding period, the B×HO steers had a greater ADG from d 29 to 84 ($P \leq 0.01$) and the HO steers tended to have a greater ADG from d 141 to 168 (P = 0.08). Overall, the B×HO steers tended to have a 5% greater ADG than the HO steers from d 0 to harvest (P = 0.07). Several studies have also shown that straightbred HO steers tend to gain slower when compared with beef breeds and beef × dairy crossbreds (Cole et al., 1963; Fahmy and Lalande, 1975; Duff and McMurphy, 2007; Basiel and

Felix, 2022). Similarly, Rezagholivand et al. (2021), observed that B×HO steers sired by AN, Charolais (CH), LM, and INRA 95 (a composite of CH, LM, Blonde d'Aquitane, Maine-Anjou, Piedmontese and Belgian Blue breeds) had a 7 to 10% greater ADG than straightbred HO steers over an 11-mo feeding period. Furthermore, two studies by Kempster et al. (1982, 1988) reported that CH × British Friesian steers gained 0.05 to 0.10 kg/d more than purebred British Friesian and Canadian HO steers. In contrast, a study by Forrest (1977) found that ADG was similar between CH × HO and purebred HO steers. Recent work by Jaborek et al. (2019b) suggested that AN-sired steers out of Jersey dams may have the most beneficial genetics for performance in beef × Jersey systems in a study that included AN, SMAN and Red Wagyu sired steers, as well as straightbred Jersey steers. As such, breeders should practice intentional selection criteria when selecting sires of B×HO offspring, as sires within breeds can significantly impact the resulting performance of beef × dairy steers.

Dry matter intake did not differ between breed types within 28-d periods ($P \geq 0.35$) or from d 0 to harvest ($P = 0.85$). Although dairy-type cattle have higher energy requirements than beef breeds due to their more metabolically active internal organs and fat depots (Garett, 1971), there is variability in DMI results between these breed types in the literature. For instance, in a study by Forrest (1981) LM × HO steers consumed 16 to 18% less per day compared with HO steers. In contrast, a study by Jaborek et al. (2019a) found that when compared with Jersey steers, beef × Jersey steers consumed 1.05 kg more DM per day.

When comparing beef and beef × dairy crossbreds with straightbred HO steers, researchers commonly report a greater G:F (Bech Andersen et al., 1977; Forrest, 1977; Long, 1980; Hardy and Fisher, 1996; Barton et al., 2006; Rezagholivand et al., 2021). We found that B×HO steers were 4% more feed efficient than HO steers from d 0 to harvest ($P = 0.01$), and this was heavily influenced by the fact that B×HO steers had a greater G:F ($P < 0.01$) at the end of the feeding period from day 225 until harvest compared with HO steers. Other studies have reported similar findings, such as a study by Forrest (1981) who which found that LM × HO steers were 18 to 21% more feed efficient than HO steers. Likewise, Rezagholivand et al. (2021) which found that CH × HO steers were 9 to 13% more feed efficient than purebred HO steers. However, some studies have reported no difference in feed efficiency between dairy and beef × dairy crossbreds (Purwin et al., 2016; Jaborek et al., 2019b).

Large frame size is a packer concern due to large dairy-type carcasses having the potential to touch or drag across the floor or equipment and affect sanitation and food safety (Eastwood et al., 2017). In the present study, HO steers had a final hip height that was 9.4 cm greater than B×HO steers ($P < 0.01$; Table 3), while B×HO steers had a more moderate frame score that was 1.9 units less than HO steers ($P < 0.01$). Forrest (1977, 1980, 1981) showed that when harvested at a similar target final BW, HO steers were taller than SM × HO and LM × HO steers. Similarly, Rezagholivand et al. (2021) observed that HO steers had a greater frame size when compared with AN × HO, CH × HO, LM × HO and INRA 95 × HO steers. Therefore, beef genetics seem to have a positive influence on moderating frame size of HO genetics and may help alleviate some packer concerns with dairy-type carcasses being too long for the abattoir.

Researchers have observed that beef breeds exhibit superior health compared with dairy breeds (Duff and McMurphy, 2007; McCabe et al., 2022). However, a study by Long (1980) observed similar disease and parasite resistance between straightbred dairy and beef × dairy calves. We also observed no significant difference in morbidity and mortality percentages between the two breed types (Table 4).

Liver and lung lesions

We found 39% of livers from the B×HO steers had abscesses, with 16% of total livers scoring A and 23% scoring A^+. Foraker et al. (2022a) collected data from cattle fed at several feedlots and found that beef × dairy crossbreds exhibited an abscess rate ranging from 40 to 60%, although they observed wide variations in liver abscess incidence among feedlots. Amachawadi and Nagaraja (2016) reported that straightbred dairy cattle have a higher incidence of liver abscesses (50 to 80%) compared with beef cattle (15 to 30%), so it is expected that beef × dairy crossbreds would have an intermediate incidence of liver abscesses. Generally, HO and beef × dairy bull calves are weaned early and sent to calf raisers that feed grain-based diets. In contrast, beef bull calves are typically raised on extensive grazing operations and have access to milk for longer periods and as such, they are able to adapt to a grain-based diet at a slower pace than HO calves (Maas and Robinson, 2007). The incidence and severity of liver abscesses has been observed to increase as roughage levels decrease (Harvey et al., 1968; Foster and Wood, 1970; Brent, 1976; Gill et al., 1979; Zinn and Plascencia, 1996). Therefore, a greater incidence of liver abscesses in beef × dairy crossbreds may be a result of feeding a grain-based diet from an earlier age and greater length of time in the feedlot compared with their beef contemporaries.

At harvest, we observed that 79% of the B×HO lungs appeared healthy with a score of 0, while 19% were observed to have 10 to 40% consolidation and only 2% had ≥ 50% consolidation. These observations align with the low morbidity shown by the B×HO steers throughout the trial.

Carcass Characteristics

The carcass characteristics of B×HO and HO steers are presented in Table 5. The HCW of B×HO and HO steers were similar (P = 0.78). Kempster et al. (1982) concurred with this finding by reporting the HCW of SM- and South Devon-sired British Friesian steers did not differ from straightbred British Friesian steers. Kempster et al. (1982) also discovered CH × British Friesian steers yielded heavier carcasses than AN × British Friesian steers. Although it was anticipated that beef genetics would reduce KPH, it was not different between breed types ($P = 0.71$). While there is not much data comparing KPH between dairy and beef-type cattle, its influence is important in carcass yield (Cole et al., 1964).

Dressing percentage of B×HO steers was numerically greater than HO steers (59.1 vs. 57.9%; $P = 0.31$). Several studies have reported that beef × dairy crossbreds have greater dressing percentages than straightbred dairy heifers and steers (Forrest, 1977, 1980, 1981; Rezagholivand et al., 2021). The dressing percentage for the B×HO steers was between those reported for beef (63%) and dairy-type (58%) cattle in the 2016-National Beef Quality Audit (Boykin et al., 2017).

Measured 12th rib FT has been reported to be similar between beef × dairy and straightbred dairy carcasses (Urick et al., 1974; Baker et al., 1984; Jaborek et al., 2019a, b), although, British-sired beef × dairy steers may produce more fat than their continental-sired contemporaries (Basiel and Felix, 2022). In the present study, B×HO steers produced carcasses with 0.39 cm more 12th rib FT than HO steer carcasses ($P < 0.01$).

Longissimus muscle area was 20% greater for B×HO steer carcasses compared with HO steer carcasses ($P < 0.01$). Similarly, Kempster et al. (1988) reported CH × Friesian and LM × Friesian steers exceeded their dairy counterparts in LMA. In contrast, beef × Jersey crossbreds in studies by Baker et al. (1984) and Jaborek et al. (2019a, b) had similar LMA to straightbred Jersey cattle. In the present study, B×HO steers produced more muscular carcasses as evidenced by a 22% greater LMA:HCW ratio than HO carcasses ($P < 0.01$). As a result of their larger

LMA, calculated USDA Yield Grade (YG) was less for B×HO steer carcasses in comparison with HO steer carcasses ($P = 0.02$). Carcass yield has often been observed to be greater for beef compared with HO carcasses (Hessle et al., 2019; Moreira et al., 2021). Therefore, beef × dairy steers may produce more carcasses that are intermediate in product yield between beef- and dairy-type cattle and result in fewer discounts for carcasses grading USDA YG 4 and 5 (Foraker et al., 2022a). However, the USDA YG equation has been observed inaccurately predict the retail yield of different breed types (Jaborek et al., 2020). Future research is needed to determine actual carcass red meat, fat, and bone yields of beef × dairy steers relative to beef and dairy-type counterparts to determine true carcass value from carcass cutout data.

Dairy cattle have contributed positively to the U.S. beef QG. According to the 2016 National Beef Quality Audit, dairy-type carcasses had the greatest average QG and marbling score compared to carcasses representing native or *Bos indicus* type cattle (Boykin et al., 2017). Moreover they comprised about 32% of carcasses grading USDA Prime QG in the same audit, yet only 16% of carcasses were classified as dairy-type (Boykin et al., 2017). The positive influence of dairy cattle genetics on marbling may be partially retained in beef × dairy crossbreds. Data collected from several commercial feedlots by Foraker et al. (2022a) found between 35 and 45% of beef × dairy carcasses exhibited Modest^0 or greater marbling scores and would meet QG specifications for many branded beef programs. In the present study, marbling scores ($P = 0.62$), USDA QG ($P > 0.52$), and cEBF ($P = 0.11$) were similar between the breed types. Using ultrasound measures overpredicted EBF by 2.2% (B×HO) and 3.2% (HO) compared with cEBF. Overprediction may have resulted from the use of fixed factors to convert live BW to HCW (Tedeschi et al., 2004), the inaccuracy of using ultrasound to estimate carcass traits (McLaren et al., 1991), and the changes in body composition from ultrasound to harvest.

The marbling scores obtained by the B×HO and HO carcasses were less than that typically expected from dairy-type cattle in across U.S. production systems (Lovell et al., 2022). To achieve greater marbling scores and greater USDA QG, the ideal harvest endpoint would likely have required additional days on feed and a greater EBF percentage for both breed-types.

Skeletal maturity of B×HO steer carcasses was greater ($P < 0.01$), but lean maturity was less ($P < 0.01$) than HO steer carcasses. However, steers of both breed types were within an approximate age range of 13 to 14 mo and differences in skeletal and lean maturity scores are unlikely to be biologically important and (or) unnoticeable to the consumer.

The B×HO steers produced carcasses that were lighter (L*), redder (a*), and more yellow (b*) than those of HO carcasses ($P < 0.01$). The B×HO carcasses had greater L* ($P = 0.01$) compared with HO carcasses. Compared with beef cattle, dairy cattle have a greater proportion of oxidative muscle fibers in their LM, which may yield darker steaks with faster rates of discoloration (Picard and Gagaoua, 2020). However, steaks from beef × dairy steers have not been reported to follow discoloration rates previously reported when compared with dairy steers (Frink, 2021; Foraker et al., 2022b). Greater discoloration of steaks from dairy steers compared with beef steers has been shown to be a source of discrimination from beef consumers (Hood and Allen, 1971). These color differences reported from the present study are not likely to affect the willingness of the consumer to purchase steaks from beef × dairy cattle, as beef genetics seem to moderate lean color of the crossbred LM when compared with the LM of dairy cattle.

Cost of Gain

The actual purchase cost of the B×HO feeder calves was \$309/calf greater ($P < 0.01$) than the HO feeder calves (Table 6). As a result, the cattle interest charge was also greater for the B×HO steers ($P < 0.01$) compared with HO steers. Total feed cost was \$95 greater for HO steers compared with the B×HO steers ($P < 0.01$), primarily because HO steers remained on feed for an additional 21 d. As a result of the study's design, non-feed operating costs were the same between both breed types for most items, however, the subtotal of these costs were greater for HO steers ($P < 0.01$) because of their extended days on feed resulting in a greater yardage cost. As a result of the feed and non-feed operating costs being less for B×HO steers, their total cost of gain was \$0.16/kg less than HO steers ($P < 0.01$).

Carcass value

Compared with dairy cattle, beef × dairy cattle have been observed to produce carcasses with greater value due to their improved muscling and yield (Forrest, 1977, 1980, 1981). Early adoption of beef × dairy crossbreeding systems has also focused on producing cattle that may capture premiums from branded programs that specify a black-hided phenotype, such as Certified Angus Beef (Pereira et al., 2022).

In the current marketplace, carcasses of B×HO cattle may be assigned a different base carcass prices depending on their conformation (beef- or dairy-type), which affects their relative value. Comparisons of four pricing scenarios, based on varying conformation for B×HO carcasses, shown in Table 7. Carcass value of B×HO carcasses in scenario 1(priced as HO) was similar compared with the HO carcasses after premiums and discounts were applied ($P = 0.60$). The B×HO carcasses in scenario 2 (priced as intermediate), scenario 3 (priced as beef) and scenario 4 (priced by carcass conformation), had a greater carcass value than those in scenario 1 ($P < 0.05$). When compared with the HO carcasses, B×HO carcasses had an \$11.39/100 kg and \$21.39/100 kg greater value in scenarios 2 and 3, respectively ($P < 0.05$). Based on LM shape, we identified 41 B×HO carcasses to be beef-type, while 15 had a dairy-type conformation. However, only 5 B×HO carcasses would have met Certified Angus Beef program specifications and received that brand premium in scenario 4. This resulted in these carcasses having a \$19.91/100 kg greater value in scenario 4 compared with HO carcasses ($P < 0.05$).

Total carcass revenue was similar between pricing scenarios 1 and 2 ($P > 0.05$) and was also similar between pricing scenarios 2, 3 and 4 ($P > 0.05$). Compared with carcasses from scenario 1, B×HO carcasses in scenarios 3 and 4 had a \$72.28 and \$68.16 greater revenue, respectively ($P < 0.05$) as carcass value increased due to greater beef conformation.

Compared with those in scenario 1, B×HO feeder calves in scenarios 3 and 4 had \$42.76/100 kg and \$39.87/100 kg greater breakeven feeder calf value, respectively ($P < 0.05$) due to their increased carcass revenue. The presented data also show B×HO feeder calves have greater potential value than HO feeder calves. Breakeven feeder calf value was greater in scenarios 1 (\$42.06/100 kg), 2 (\$63.44/100 kg), 3 (\$84.82/100 kg), and 4 (\$81.93/100 kg) compared with the HO steers ($P < 0.05$), which is primarily attributed to the overall lesser cost of gain of the B×HO steers. Based on their receiving BW, B×HO feeder calves purchased for this study would have been worth \$72.30 to \$145.81/calf more compared with the HO feeder calves.

Implications

Overall, B×HO steers tended to have a faster rate of gain and were more feed efficient when compared with their HO contemporaries during the finishing period. Health, DMI, and most carcass traits were similar with the notable difference of larger LMA observed in B×HO carcasses. The B×HO steers had a greater carcass value and breakeven feeder calf value. These results show that breeding beef sires to dairy dams can result in steers capable of attaining a beef-type conformation to qualify for branded beef programs such as Certified Angus Beef. Further research is necessary to understand how to consistently produce B×HO carcasses with conformation and value similar to beef-type carcasses.

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Tables

Table 2-1. Composition of starter and finishing diets

	Diets	
Ingredient	Starter	Finishing
	--Percentage of diet DM--	
Dry whole shelled corn	66.0	-
Whole oats	15.3	-
Pelleted supplement[1]	18.3	-
Molasses	0.42	-
Chopped hay	29.1	-
High moisture shelled corn	-	43.6
Corn silage	-	25.0
Dry corn distillers grains with solubles	-	25.3
Pelleted supplement[2]	-	5.0
Limestone	-	1.1
Item		
	--Percentage of diet DM--	
Crude protein	13.4	14.8
aNDF	27.2	22.0
Ca	0.53	0.90
P	0.53	0.46
	--Mcal/kg--	
NE_m	1.80	2.04
NE_g	1.17	1.36

[1]Calculated analysis on a DM basis provided by the manufacturer: monensin (176 mg/kg), crude protein (36%), Ca (2.5%), K (1.2%), P (0.7%), and vitamin A (5398 IU/kg).

[2] Calculated analyses on a DM basis provided by the manufacturer: monensin (529 mg/kg), crude protein (50%), Ca (8.4%), K (3.7%), P (0.3%), vitamin A (12927 IU/kg), vitamin D_3 (1610 IU/kg) and vitamin E (209 IU/kg).

Table 2-2. Genomically determined breeds of the beef × Holstein crossbreds

Sire breed	n	%
Angus	18	35.3
Limousin	14	27.5
LimFlex[1]	6	11.8
Simmental	4	7.8
SimAngus[2]	9	17.6
	51	100.0

[1] Limousin × Angus
[2] Simmental × Angus
[3] 7 samples were not able to be analyzed by the laboratory.

Table 2-3. Feedlot growth and finishing performance of straightbred Holstein and beef × Holstein steers

	Breed type			
Item	Holstein	Beef × Holstein	SEM[1]	*P*-value
Number of pens	10	10	-	-
Days on feed	266	245	-	-
Body weight, kg				
Initial	197.1	196.9	1.7	0.8876
d 28	233.1	233.9	1.8	0.6870
d 56	274.6	278.7	2.5	0.1398
d 84	321.4	334.3	2.9	0.0017
d 112	372.3	387.2	2.7	0.0004
d 140	422.7	438.1	3.0	0.0006
d 168	480.6	494.6	3.1	0.0016
d 196	535.6	549.4	4.5	0.0132
d 224	579.3	593.4	5.5	0.0305
Final BW	635.4	622.0	6.3	0.0617
Average daily gain, kg/d				
d 0-28	1.29	1.33	0.04	0.3411
d 29-56	1.48	1.60	0.05	0.0105
d 57-84	1.67	1.98	0.07	< 0.0001
d 85-112	1.82	1.90	0.07	0.2310
d 113-140	1.80	1.82	0.06	0.7457
d 141-168	2.07	1.92	0.08	0.0780
d 169-196	1.97	1.89	0.07	0.2899
d 197-224	1.55	1.57	0.12	0.8528
d 225-harvest	1.23	1.31	0.11	0.4431
d 0-harvest	1.62	1.70	0.05	0.0741
Dry matter intake, kg/d				
d 0-28	5.96	5.99	0.22	0.8812
d 29-56	7.43	7.39	0.23	0.8538
d 57-84	9.25	8.98	0.29	0.3533
d 85-112	9.80	9.76	0.25	0.8806
d 113-140	11.66	11.89	0.36	0.5255

Table 2-3 (cont'd)

Item	Breed type		SEM[1]	*P*-value
	Holstein	Beef × Holstein		
d 141-168	12.49	12.41	0.20	0.6836
d 169-196	13.15	13.12	0.36	0.9230
d 197-224	13.25	13.29	0.64	0.9542
d 225-harvest	13.26	12.76	0.58	0.3877
d 0-harvest	10.69	10.62	0.40	0.8521
Gain:feed, kg/kg				
d 0-28	0.228	0.213	0.009	0.1017
d 29-56	0.206	0.209	0.007	0.6679
d 57-84	0.199	0.203	0.010	0.6934
d 85-112	0.193	0.191	0.007	0.7712
d 113-140	0.154	0.150	0.004	0.3081
d 141-168	0.158	0.160	0.007	0.7873
d 169-196	0.151	0.143	0.006	0.1712
d 197-224	0.111	0.124	0.008	0.1184
d 225-harvest	0.093	0.154	0.018	0.0011
d 0-harvest	0.166	0.172	0.006	0.0125
Hip Height, cm	148.5	139.1	0.5	< 0.0001
Frame Score[2]	9.4	7.5	0.1	< 0.0001

[1] Standard error of the mean.
[2] Calculated using the equation for bulls (BIF, 2023) assuming all steers were born on the same day.

Table 2-4. Morbidity and mortality of straightbred Holstein and beef × Holstein steers

	Breed type			
Item	Holstein	Beef × Holstein	SEM[1]	*P*-value
Number of steers	60	60	-	-
Treated 1 time, %[2]	8.3	10.0	0.6	0.7526
Treated 2 times, %[2]	1.7	1.7	1.4	1.0000
Mortality,%[3]	1.7	3.3	1.3	0.5675

[1] Standard error of the mean.

[2] Antibiotic treatment was administered to steers pulled from their pens with signs of morbidity that had a rectal temperature of ≥ 37°C.

[3] One B×HO steer died (d 84), one B×HO steer was euthanized due to a leg injury (d 243), and one HO steer died after being found inverted in the feed bunk (d 196).

Table 2-5. Carcass characteristics of straightbred Holstein and beef × Holstein steers harvested at similar percentages of empty body fat

	Breed type			
Item	Holstein	Beef × Holstein	SEM[1]	*P*-value
Number of pens	10	10	-	-
Days on feed	266	245	-	-
HCW, kg[2]	366.6	365.4	3.9	0.7765
Dressing percentage, %	57.9	59.1	1.0	0.3094
LMA, cm^2 [3]	73.1	87.8	1.5	< 0.0001
FT, cm [4]	0.79	1.18	0.1	0.0004
KPH, %	2.6	2.6	0.1	0.7093
Calculated Yield Grade[5]	3.2	2.9	0.12	0.0212
LMA:HCW, cm^2/100 kg	11.6	14.2	0.4	0.0002
Marbling score[6]	437.1	426.7	20.8	0.6216
Carcass empty body fat (cEBF), %[7]	27.6	28.4	0.4	0.1129
USDA QG				
Prime, %	1.7	3.6	1.2	0.5287
High-Choice and higher, %	6.8	7.3	0.7	0.9182
Mid-Choice and higher, %	20.3	18.2	0.5	0.7712
Low-Choice and higher, %	59.3	54.5	0.4	0.6079
Select and higher, %	100.0	100.0	0.0	1.0000
Skeletal maturity[8]	155.4	167.9	2.3	0.0004
Lean maturity[8]	203.0	165.1	3.7	< 0.0001
Lean color[9]				
L*	34.0	35.2	0.3	0.0087
a*	16.4	19.3	0.3	< 0.0001
b*	11.6	13.4	0.2	< 0.0001

[1] Standard error of the mean.
[2] Hot carcass weight; Before kidney, pelvic, and heart fat removal.
[3] Longissimus muscle area
[4] Fat thickness
[5] Yield grade = 2.5 + (2.5 × (FT /2.54)) + (0.2 × KPH) + (0.0038 × (HCW 1/0.453592)) - (0.32 × (LMA/6.4516)).
[6] Marbling scores are based on a numeric scale: 300-399 = slight, 400-499 = small, and 500-599 = modest.
[7] cEBF, % = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) - (0.06754 × LMA).
[8] Expressed using a scale where 100 = $A^{00}$and 200 = B^{00}.
[9] CIE L* = lightness, a* = redness, and b* = yellowness.

Table 2-6. Total costs of straightbred Holstein and beef × Holstein steers

Item	Breed type: Holstein	Breed type: Beef × Holstein	SEM[1]	*P*-value
Number of pens	10	10	-	-
Days on feed[2]	287	266	-	-
Purchase cost, $/steer[3]	$540.33	$849.56	10.9	< 0.0001
Interest on cattle, $/steer[4]	$21.24	$30.96	0.38	< 0.0001
Feed costs, $/steer				
Pre-trial feed cost	$35.29	$38.49	-	-
Starter feed cost	$60.61	$58.87	0.92	0.0048
Finisher feed cost	$822.53	$730.37	15.3	0.0002
Interest on feed	$18.05	$15.05	0.29	< 0.0001
Subtotal	$936.48	$841.07	15.59	0.0002
Non-feed operating costs, $/steer				
Preventative health	$21.44	$21.44	-	-
Medication	$2.21	$2.43	1.62	0.8933
Death loss[5]	$10.42	$17.42	20.22	0.7298
Implants	$6.90	$6.90	-	-
Yardage[6]	$287.00	$266.00	-	-
Transportation to harvest	$21.83	$21.83	-	-
Beef Checkoff	$1.00	$1.00	-	-
Subtotal	$361.62	$350.56	1.69	< 0.0001
***Cost of gain, $/kg*[7]**	$2.81	$2.64	0.05	0.0055

[1] Standard error of the mean.
[2] Includes pre-trial period.
[3] Includes transportation from the calf raiser to the feedlot.
[4] Interest rate on the cattle was 4.53%.
[5] Includes vaccination, metaphylaxis, and deworming. Sum of purchase cost and preventative health divided over all steers.
[6] Yardage included management, taxes, insurance, interest on facilities, machinery, facility repairs, fuel, oil, utilities, depreciation, and bedding and was included as $1.00 • steer^{-1} • d^{-1}.
[7] Cost of gain per kg was calculated by dividing the total operating costs by total BW gained from delivery to harvest.

Table 2-7. Pricing Scenarios for Beef × Holstein steers priced as Holstein, beef × Holstein, or beef carcasses

		Beef × Holstein carcass pricing scenarios				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	
Item	Holstein	Priced as Holstein	Priced as intermediate	Priced as Beef	Priced by carcass conformation	SEM[1]
Base carcass price, \$/100 kg[2]	\$493.92	\$493.92	\$503.84	\$513.77	Variable	-
Carcass value, \$/100 kg[3]	\$492.65[a]	\$494.08[a]	\$504.04[b]	\$514.04[c]	\$512.56[c]	24.50
Total carcass revenue, \$/carcass[4]	\$1,799.97[a]	\$1,799.83[a]	\$1,835.97[ab]	\$1,872.11[b]	\$1,867.99[b]	42.67
Breakeven feeder calf value, \$/100 kg[5]	\$305.02[a]	\$347.08[b]	\$368.46[bc]	\$389.84[c]	\$386.95[c]	22.47

[a–d] Holstein and pricing scenario lsmean estimates in the same row with a different superscript differ ($P < 0.05$).
[1]Standard error of the mean reported as the greatest SEM among the pricing scenarios.
[2]Base carcass price for HO was assigned by the abattoir. Base carcass price for scenario 1 was equal to that of the HO. Base carcass price for scenario 2 was an average of the beef (Scenario 3) and Holstein base carcass prices. Base carcass price for scenario 3 was assigned by the abattoir. Base carcass price for scenario 4 was equal to Scenario 2 for carcasses with dairy-type conformation and equal to Scenario 3 for carcasses with beef-type conformation.
[3]Carcass price after applying premiums and discounts.
[4]Carcass value multiplied by the HCW.
[5]Calculated by subtracting the total cost of gain from the total carcass revenue and then dividing by the purchase weight.

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CHAPTER 3: IMPLICATIONS AND CONCLUSIONS

Implications and Conclusions

The Holstein (HO) breed is often associated with having a greater dry matter intake (DMI) due to their greater visceral organ mass, greater maintenance requirements and requiring a greater number of days on feed compared with beef-type cattle. While these traits are negative and expected from HO cattle, they also show a desirable consistency of traits compared with beef breeds. Additionally, beef abattoirs may be reluctant to purchase beef × Holstein (B×HO) steers as there may be variability due to sire breed differences. Breeding carefully selected beef bulls to low production dairy dams is a management practice that may increase calf revenue; however it may be questioned how profitable these calves are throughout the supply chain. To sustain premiums for B×HO feeder calves, compared with straightbred HO steers, the true value of B×HO cattle must be understood so that the competitive market demands of the beef industry can be met.

The research conducted observed differences of B×HO steers compared with straightbred HO steers in feedlot growth, finishing performance, carcass yield, and value. Health and DMI of B×HO steers in the present study were similar to HO steers. However, B×HO steers had smaller frame scores and more desirable feed efficiency, with a tendency for 5% greater ADG compared with HO steers. An equitable harvest endpoint was determined by harvesting both breed types at an average 30.7% predicted empty body fat (EBF). Post-harvest EBF calculated from carcass measures resulted in an average 28.0%, and as a result, carcasses had lower USDA quality grade (QG) than expected with nearly 43% of the carcasses grading USDA Select. Therefore, the equation used to predict EBF using ultrasound overpredicted EBF by an average of 2.7%, compared with that predicted from carcass measures, which may have been a result of using fixed factors to convert live BW to HCW, estimating carcass traits via ultrasound which has inaccuracies, and the changes in body composition from ultrasound to harvest. A third ultrasound point and additional days on feed may have benefited the steers, as they may have finished at a greater EBF and resulted in carcasses having improved marbling scores and USDA QG.

The smaller of frame size B×HO steers would help resolve a packer concern regarding HO steer carcasses being too large on the rail. The B×HO carcasses had a greater back fat thickness (FT), but kidney, pelvic, heart fat (KPH) was similar when compared with HO steers, even though it may have been expected for the crossbreds to have a lesser percentage of internal fat. Compared with the HO carcasses, longissimus muscle area (LMA) was 20% greater for the B×HO crossbreds, and similarly, calculated carcass yield was more desirable for B×HO carcasses based on the USDA YG equation. This resulted in a greater value for the B×HO carcasses compared with the HO carcasses. The greater base carcass price of the B×HO carcasses in pricing scenarios 2, 3, and 4 resulted in greater carcass value for the B×HO steers relative to HO carcasses. Furthermore, breakeven feeder calf value was greater for the B×HO calves in all pricing scenarios compared with the HO feeder calves, primarily as a result of B×HO steers lower cost of gain. Based on their receiving BW, B×HO feeder calves purchased for this study would have been worth between $72.30 and $145.81/calf more compared with the HO feeder calves, depending on their carcass pricing.

Future research should compare the variability of different sire breeds in beef × dairy crossbred feeder steers and the resulting effects on performance and carcass traits. The current body of literature is not consistent and more recent data in the U.S. is lacking for beef × dairy production systems. Furthermore, European studies, while helpful, may not be reliable examples due to the vast differences among breed genetics and production systems when compared with the U.S. To meet the needs and expectations of both the beef and dairy industries, intentional selection criteria should be used when selecting beef sires for dairy dams. As an emerging sector of the industry, future breeding goals should be directed towards raising beef × dairy cattle that improve upon those found in the current supply chain that could potentially meet specifications and resulting premiums of the Certified Angus Beef program. The results from the present study show that breeding beef sires to dairy dams can result in steers capable of attaining a beef-type conformation to qualify for branded beef programs, such as Certified Angus Beef. Further research is necessary to understand how to consistently produce B×HO carcasses with beef-type conformation and value of beef-type carcasses.

APPENDIX A: Supplemental tables

Table A-1. Pre-trial health of straightbred Holstein and beef × Holstein steers

	Breed type			
Item	Holstein	Beef × Holstein	SEM	*P*-value
Number of steers	75	75	-	-
Treated 1 time, %[1]	4.0	5.3	0.8	0.6826
Treated 2 times, %	1.3	1.3	0.2	1.00
Treated 3 times, %	0.0	1.3	0.6	0.9804
Morbidity, %	4.0	5.3	0.8	0.6826

[1]Antibiotic treatment was administered to calves pulled from their pens with signs of morbidity that had a rectal temperature of ^{3} 37°C.

Table A-2. Manure scores of straightbred Holstein and beef × Holstein steers

	Breed type			
Item	Holstein	Beef × Holstein	SEM	*P*-value
Number of pens	10	10	-	-
Manure scores[1]				
d 112	1.3	1.5	0.1	0.0013
d 140	1.2	1.5	0.1	0.0002
d 168	1.0	1.1	0.1	0.5424
d 224	1.0	1.1	0.1	0.7327
At harvest	1.2	1.2	0.1	0.5023
d 112-harvest	1.1	1.3	0.1	0.0346

[1]Based on the Iowa State University Extension and Outreach and Beef Quality Audit mud and manure scoring system where 1 = clean hide, 2 = small lumps of mud in limited areas of legs, side and underbelly, 3 = small and large lumps of mud in large areas of legs, side and underbelly, 4 = small and large lumps of mud in even larger areas along the hindquarter, stomach, and front shoulder, 5 = Lumps of manure on hide continuously on the underbelly and side of the animal from front to rear.

APPENDIX B: SAS Code

X = Response variable (e.g., ADG, DMI, G:F)

Feedlot performance

```
Proc mixed data=BxHO Plots=all;
class Breed Pen Rep Block Day;
model X=Breed|Day;
random Pen(Block);
repeated Day/type = cs subject = Pen(Breed);
lsmeans Breed|Day/pdiff slice=(Breed Day);
run;
```

Morbidity and Mortality

```
Proc freq data = BxHO nlevels;
tables X*Breed/fisher;
run;

Proc glimmix data=BxHO Plots=residualpanel;
class Breed Pen Rep Block;
model X (event='1') = Breed/dist=binary ddfm = satterth;
lsmeans Breed/pdiff ilink;
run;
```

Carcass characteristics and economic analysis

```
proc mixed data=BxHO Plots = all;
class Breed Pen Rep Block;
model X=Breed;
random Pen(Block);
lsmeans Breed/pdiff;
run;
```

Quality grade

```
Proc freq data=BxHO nlevels;
tables X*Breed/fisher;
run;

Proc glimmix data=BxHO Plots=residualpanel;
class Breed Pen Rep Block;
model X (event='1')=Breed/dist=binary ddfm = satterth;
lsmeans Breed/pdiff ilink;
run;
```

Pricing scenarios

```
Proc mixed data=BxHO Plots=all;
class Breed Pen Rep Block ID PricingScenario;
model X= PricingScenario;
random Pen (Block);
lsmeans PricingScenario/pdiff adjust = Tukey;
run;

Proc glm data=BxHO;
class Breed Pen Rep Block ID PricingScenario;
model X= PricingScenario;
means PricingScenario/Tukey;
means PricingScenario/duncan waller;
run;
```