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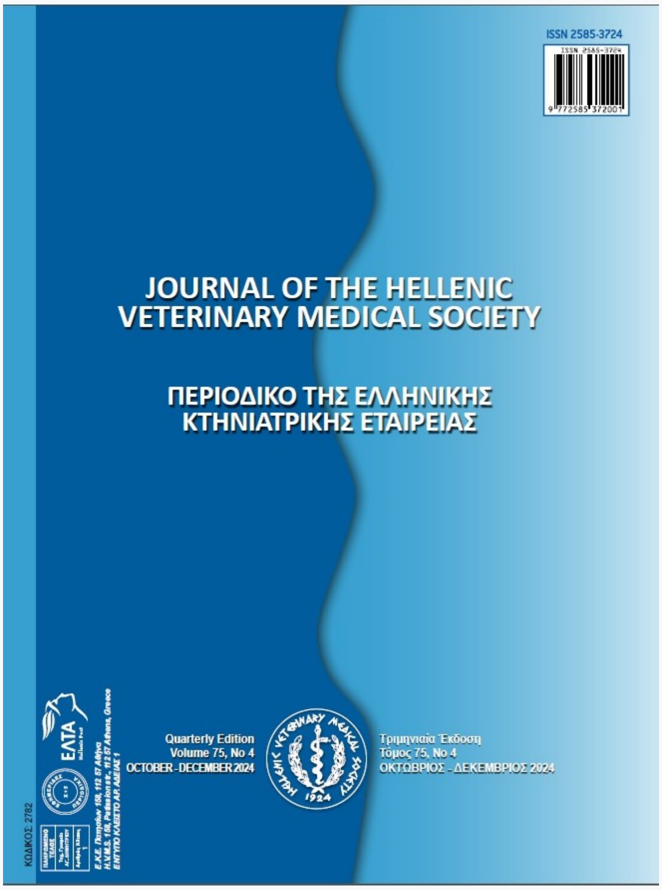

Important aspects on beef-cross-dairy breeding related to reproduction and the traits of calves

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Review article
Ανασκόπηση

Important aspects on beef-cross-dairy breeding related to reproduction and the traits of calves

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ABSTRACT: Crossbreeding between beef sires and dairy dams is not a new concept; it is one of the first practices used on dairy herds. Generally, in dairy farms calves produced, that are not used for replacement animals, are usually sold to fattening units. Due to growth restriction and poor carcass quality of these purebred dairy calves, it is important to reintroduce the beef × dairy crossbreeding to dairy farms for producing more valuable calves. To accomplish the most economic gain from the breeding strategy for crossbreeding, reproductive indices such as conception rate, gestation length, calving difficulty and calf mortality of the beef × dairy crossbreeding animals should be taken into consideration, as well as beef sire's genetics transmitted ability. Moreover, important factors for beef-cross-dairy calf production are the feed intake and the quality of the carcass as well as some visual characteristics containing weight at birth, coat color, polledness and docility. Lastly, understanding the dairy farmers' attitude to sire selection and the consumers' meat preferences could provide valuable information about improving the efficiency of this breeding strategy. In conclusion, beef × dairy crossbreeding could increase meat production especially in countries in need, although more research is needed about synchronization protocols for artificial insemination with beef or sexed beef semen to dairy cows.

Key words: beef × dairy calves; characteristics of calves; reproductive management

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INTRODUCTION

Traditionally, a way to increase the profitability of dairy farms is to generate beef-cross-dairy calves for fattening by crossing genetically inferior dairy cows with beef bulls (McHugh et al., 2010). Crossbreeding is not a new concept; it is probably one of the first breeding practices performed on dairy cattle, as reported by Touchberry (1992). Scientific publications that assess the efficiency of beef production from the dairy herds are dated back to at least the 1960s (reviewed in Berry, 2021). This strategy complies with farmers desire to maintain cash flow through the sale of surplus progeny for meat production. It also contributes to the increase of the herd's genetic level as the offspring of the genetically inferior cows do not enter the milking herd (Mota et al., 2022).-Furthermore, this is in accordance with increasing consumers' interest in how food is produced and the alignment with specific social issues (Mota et al., 2022).

Heterosis is the most desired "outcome" in the crossbreeding; it refers to the superiority of the crossbreds over the weighted average of their parent breeds (Berry, 2021). Crosses between dairy and beef animals are expected to give maximum heterosis given the difference in breed origins. Less heritable traits are often most impacted by heterosis, leading to the logical assumption that beef-cross-dairy calves could be more resistant to health issues than purebred dairy calves (Bourdon, 2014; Weaber, 2021).

Important traits are improved by the positive impact of beef over dairy genetics (Clasen et al., 2020; Foraker et al., 2022a). Those traits are referred to fertility, calving ability, survival rates, animal health, fewer days on feed, greater feed efficiency and increased carcass yields compared to pure-bred dairy cattle (Foraker et al., 2022a). This way, the practice of beef-dairy crossbreeding could be more sustainable than production of pure-bred dairy calves (Clasen et al., 2017; Foraker et al., 2022a).

A widespread breeding strategy is the use of female-sexed dairy semen on dams for replacement heifer production and beef semen on dairy cows (to some extent) for beef production. The economic gain of such strategy is connected to the stocking ability of the herd. The highest economic gain is observed when the following parameters exist: a) below-average stocking density, b) average cow longevity (<3 lactations per cow), c) high heifer prices, and d) semen parameters favorable for sexed semen (high conception rates and accuracy of sexed semen) (Pahmeyer and Britz, 2020). In order to achieve the highest profit for the above-mentioned farms, the use of sexed semen should be applied on all heifers as well as all cows (Cottle et al., 2018).

The main motivation for this review is to present an overview of reproductive management strategies focusing on main reproductive parameters or indexes and functional traits that are important for a successful beef × dairy crossbreeding strategy, including farmers preferences, among others.

BEEF CROSS DAIRY BREEDING STRATEGIES

There are several breeding strategies for beef crossbreeding, as well as for dairy crossbreeding. In the present review only the strategies that could be applied for beef × dairy breeding are described (Table 1).

A two-breed terminal crossbreeding system uses pure-bred dairy cows of breed D (dairy) and sires of breed B (beef) as shown in Table 1a. All the calves produced are marketed and not used as replacement animals (Weaber, 2015). Therefore, replacement females must be purchased. The terminal cross system works well for herds of any size if high quality replacement females are readily available from other sources (Weaber, 2015). In the three-breed terminal crossbreeding the only difference is that either the dam or the sire is a cross between two breeds as shown in Table 1b. All the other parameters remain the same (Weaber, 2015).

The two-breed rotation requires two different breeds of dams and sires, and the replacement females produced mated to the opposite breed of sire as shown in Table 1c (Weaber, 2015). Three-breed rotation is similar to the two-breed; however, a third breed is added as shown in Table 1d. The restriction of these systems is the number of animals in the herd, with two-breed system required at least 50 cows (Weaber, 2015). Another alteration of the rotational system is the addition of a terminal sire, called rota-terminal system. It includes a rotational and a terminal crossbreeding system with 2 different maternal breeds, the one to produce the replacement females for the entire herd and the other to be bred to a sire of a different breed (Table 1e). Minimum herd size for this system is approximately 100 cows (Weaber, 2015).

SYNCHRONIZATION PROTOCOLS AND REPRODUCTIVE INDEXES

The use of reproductive biotechnologies is an essential mean to improve productivity. Howev-

Table 1. Beef × Dairy breeding strategies

<table>
<tr>
<td>D♀ × B♂
⇩
DB calves
⇩
All calves are sold for fattening

1a Two-breed terminal crossbreeding</td>
<td>D♀ × B♂
⇩
DB♀ × D♂
⇩
DB ♀ $_{(D>B)}$ × B♂
⇅
DB ♀ $_{(B>D)}$ ×D♂
⇩
All ♂ calves are sold for fattening

1c Two-breed rotational crossbreeding</td>
<td rowspan="2">DB^1♀ × B^2♂ or D♀× B^1B^2♂
⇩
DB^1B^2♀ × D♂
⇩
DB^1B^2♀$_{(D>B^1>B^2)}$ x B^2♂
⇅ ⇅
DB^1B^2♀$_{(B^1>B^2>D)}$ ×D♂⇄DB^1B^2♀$_{(B^2>D>B^1)}$×B^1♂
⇩
All ♂ calves are sold for fattening

Or

D^1D^2♀ ×B♂ or
D^1♀ × D^2B♂
⇩
D^1D^2B × $D^1_{(B>D^2>D^1)}$
⇅ ⇅
D^1D^2B♀$_{(D^1>B>D^2)}$×D^2♂⇄D^1D^2B♀$_{(D^2>D^1>B)}$×B♂
⇩
All ♂ calves are sold for fattening

1d Three-breed rotational crossbreeding</td>
</tr>
<tr>
<td>DB^1♀× B^2♂
or D♀ × B^1B^2♂
⇩
DB^1B^2 calves
⇩
All calves are sold for fattening
or
D^1D^2♀× B♂
or D^1♀× D^2B♂
⇩
D^1D^2B calves
⇩
All calves are sold for fattening

1b Three-breed terminal crossbreeding</td>
<td>D♀ × D♂ or D♀ ×B♂
⇅ ⇩
D♀ × D♂ DB calves
⇩ ⇩
All ♂ calves are sold for fattening All calves are sold for fattening

1e Two-breed rotational crossbreeding with terminal sire</td>
</tr>
</table>

1a: Two-breed terminal crossbreeding. D (dairy dam) breeds with B (beef sire). All the produced beef×dairy calves will be sold to fattening units. None of them will enter the reproductive herd. Replacement animals in this system are purchased.

1b: Three-breed terminal crossbreeding. D (dairy dam) breeds with B^1B^2 (crossbred beef sire) or DB^1 (beef×dairy dam) breeds with B^2 (beef sire) or D^1D^2 (crossbred dairy×dairy) with B (beef sire). All the produced beef×dairy calves will be sold to fattening units. None of them will enter the reproductive herd. Replacement animals in this system are purchased.

1c: Two-breed rotational crossbreeding. D (dairy dam) breeds with B (beef sire); the producing DB (beef×dairy) replacement heifers breed with D (dairy) sire, producing DB replacement heifers (with D-(dairy breed > B-beef breed). DB replacement heifers breed with B (beef) sires, producing DB (beef×dairy) replacement heifers (with B-beef breed > D-dairy breed). The next mating depends on the proportion of each breed, with the sire breed selected is that with lower portion of the two-breed dam. All crossbred male calves in each mating sold to fattening units.

1d: Three-breed rotational crossbreeding. D (dairy dam) breeds with B^1B^2 (crossbred beef sire) or DB^1 (beef×dairy dam) breeds with B^2 (beef sire) or D^1D^2 (crossbred dairy×dairy dam) breeds with B (beef sire) or D^1 (dairy dam) breeds with D^2B (crossbred dairy×beef sire). All the produced DB^1B^2 heifers breed with D (dairy) sire producing DB^1B^2 replacement heifers (with D-dairy breed $>B^1>B^2$-beef breed or $D>B^2>B^1$) or all the produced D^1D^2B heifers breed with B (beef sire) to produce D^1D^2B replacement heifers (with $B>D^1>D^2$ or $B>D^2>D^1$). The next mating depends on the proportion of each breed, with the sire breed selected is that with lower portion of the three-breed dam. All crossbred male calves in each mating sold to fattening units.

1e: Two-breed rotational crossbreeding with terminal sire. D (dairy) dam breeds with D (dairy) sire, producing purebred dairy replacement heifers. The male purebred dairy calves will be sold to fattening units. The remaining D (dairy) dams breed with B (beef) sire producing crossbreeding (beef×dairy) calves, all of those sold to fattening units.

er, they are not always affordable in certain regions of the world or production systems, especially for small-holder farmers in developing countries. Artificial Insemination (AI) is the predominant method in beef-dairy crossbreeding, whereas natural mating is also used (Berry, 2021).

Herds with average reproductive performance achieved maximal profit from calves, when sexed dairy semen was used on all heifers' first and second services, primiparous and second-lactation cows' first service, whereas conventional dairy semen was used on remaining heifers and beef semen on remaining cows (Cabrera, 2022). Farms with relatively low replacement rates and high average cow longevity were able to take advantage of crossbred calf price by producing their replacement animals from genetically superior heifers inseminated with sexed semen and more crossbred calves from older cows (Pahmeyer and Britz, 2020). High rates of sexed beef semen usage could be applied in farms that received increased prices for crossbred calf and the conception rates with sexed semen are >90% of that with conventional semen (Pahmeyer and Britz, 2020). Finally, farms with low stocking densities maximized profits by using sexed semen to produce replacement heifers for sale, whereas farms with high stocking densities by producing crossbred calves for sale and replacement heifers by using sexed semen (Pahmeyer and Britz, 2020).

Synchronization protocols for AI with sexed semen

The synchronization protocols with sexed semen are mostly investigated for dairy dams inseminated with dairy semen. Thus, in cases we want to perform AI with sexed beef semen in dairy cows / heifers, we must follow the instructions given for dairy cows. Recent studies on the synchronization protocols used for AI of dairy heifers / cows with sexed dairy bull semen are presented in Table 2.

Fertility-Conception rate

There is few information about the conception rate on beef-cross-dairy crossbreeding. In the dairy systems, the conception rate of cows inseminated with beef sire semen is considered the most important index, whereas calf mortality at birth is the second one (Wolfová et al., 2007). In general, crossbreeding (beef-cross-dairy) seems to improve fertility compared with pure breeding (Clasen et al., 2020; Bittante et al., 2021). However, the conception rate of Holstein cows and heifers mated to Angus bulls was slightly lower compared to those mated with Holstein bulls, probably because beef sires were used on females with sub-fertility problems that led to increased AI services (McWhorter et al., 2020).

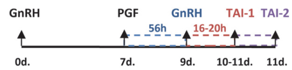
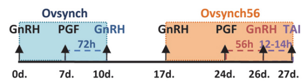
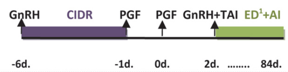
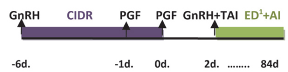
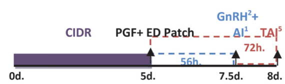
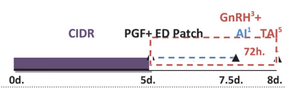
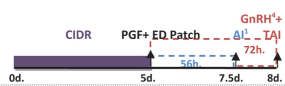
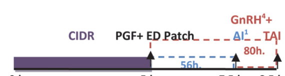
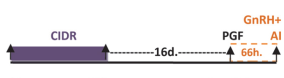
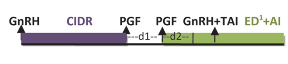
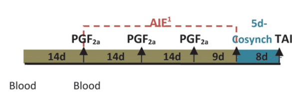
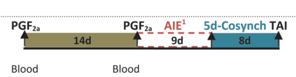
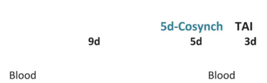
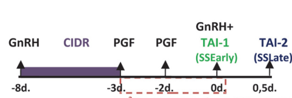
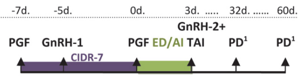
As far as we know, there are no studies concerning conception rates after AI of dairy cows/heifers with sexed beef semen. In Table 2 are presented the conception rates after estrous synchronization of dairy cows/ heifers that are artificially inseminated with sexed dairy semen. In the majority of studies, AI with sexed semen was performed in heifers. The conception rate ranged from 25.93% to 67.7% (Table 2), depending on the experimental design and the estrus synchronization protocol used. A conception rate of about 45% was found in most of the studies. These results give us a clue of what we could expect after AI with sexed beef semen.

Gestation length

Gestation length may be one of the fertility indices that could potentially affect the reproductive efficiency of dairy cows and cause calving problems such as dystocia and stillbirths (Olson et al., 2009). Shorter gestation length is associated with lower calving weight and reduced calving difficulty (Rezende et al., 2020). Consequently, selection of individual sires based on their genetic merit for gestation length could help in the overall reduction in calving problems (Coleman et al., 2021). However, longer gestation length, observed in Holstein × Limousin or Holstein × Galician Blonde calves, did not imply a more difficult calving as observed in Holstein × Belgian Blue crossbreds (Fouz et al., 2013). Furthermore, farmers' choice of sire breed for crossbreeding in terms of gestation length, does not seem to be affected by the calving difficulty, even though Belgian Blue crossbreds had more uneventful calving (Fouz et al., 2013).

There is genetic variability among breeds as concern gestation length; inter-breed differences among beef breeds mated to dairy cows have been reported for gestation length (Fouz et al., 2013; Fitzgerald et al., 2015; Berry and Ring, 2020). In dairy breeds, mean predicted transmitting ability (PTA) of dairy sire for gestation length increases from heifers to first- and second-parity cows but remains constant thereafter, whereas mean PTA of beef sire for gestation length increased with each parity (Berry et al., 2020). Shorter gestation length in dairy compared to beef bulls is well established (Fitzgerald et al., 2015). Calves from dairy bulls were expected to be born 3d earlier than

Table 2. Synchronization protocols for AI with sexed semen in dairy cows and heifers. Conception rates for each protocol.

Authors	Name of the protocol	Protocol	Pregnancy rates	Comments
Mellado et al. (2023)	**Ovsynch**		45±3d. Single dose: 51.9% Double dose: 63.4%	Services for heifers: 2.6±1.5 The results of this study should be interpreted with caution, due to limited to a single herd data. However, they support the hypothesis that double AI in a TAI protocol would increase fertility compared with a single AI.
Dawod, Ahmed, and Elbaz, Hamed T. (2020)	**Double-Ovsynch (Ovsynch for synchronization and 7d later Onsynch56 for TAI)**		Overall: 51.45% Age of Puberty: – <350d: 60.98% – 350-450d: 54.60% – >450d: 25.93%	Higher Pregnancy rate in this study could be due to the use of the nulliparous heifers instead of multiparous cows. Heifers can be inseminated with sexed semen as, reproductive parameters and fertility were higher compared with lactating cows.
Lauber, M.R., et al. (2021)	**5-d CIDR-Synch**		35±5 d. 52.9%	[1]ED: Estrus Detection 6-d CIDR-Synch in heifer suppresses early estrus expression before scheduled TAI; however, it tended to decrease P/AI. 5-d CIDR-Synch protocol tended to increase P/AI at first AI compared to 6-d CIDR-Synch.
	6-d CIDR-Synch		35±5d. 45.3%	
Macmillan, K., et al. (2021) (2 experiments with modified 5-d CO-Synch protocols)	**1.GnRH56**		28.8%	[1]AI heifers in estrus by 48h [2]GnRH in heifers not inseminated [3]GnRH all heifers [4]GnRH heifers not in estrus [5]TAI: timed-AI Timing of GnRH administration had no effect on estrus or P/AI. The results suggest GnRH before TAI does not improve fertility. P/AI was increased in heifers that display estrus before AI.
	1.GnRH72		30.3%	
	2.TAI72		28d. 67.7%	Delaying AI to 80h increased the proportion of heifers in estrus at AI compared with AI at 72h. However, there was no difference in P/AI between TAI72 and TAI80 groups at either 28d or 42d post TAI. The estrus rate was increased in the TAI80 group as compared to TAI72, however there was no difference in P/AI between groups.
	2.TAI80		28d. 65.7%	
Mallory, D. A., et al. (2013)	**Show-Me-Synch**		30-43% (avg. 38%)	The experiment had taken place in two different locations. The results show that location had no effect on Reproductive Tract Score. Heifers exhibited estrus before AI, tended to have greater P/AI, than heifers that failed to exhibit estrus.
Silva, T. V., et al. (2015)	**5-d CO-Synch**		54.8%	Approximately 26.9% of the TAI Heifers were inseminated on d 1 of the study. The remaining heifers were inseminated on d 2. The P/AI was numerically lower but not statistically different for heifers display or not estrus.
Masello, M., et al. (2019) (3 Presynch-like protocols)	**PGF + AIE**		31±3d Overall: 42% Before Cosynch:44%	[1]AIE= artificial insemination at detected estrus. The total rate of heifers that received AIE was greater for the PGF+AIE group than PGF+TAI as concern the 1[st] service. PI/AI was similar for AIE and TAI services.
	PGF + TAI		Overall: 47.3% 1[st] PGF_{2a}: 52.9% During Cosynch: 45% TAI: 29%	
	ALL TAI		Overall: 43.8% During Cosynch: 47.1% TAI: 41.4%	
Chebel, Ricardo C., and Thiago Cunhia (2020) (5d-Cosynch with different TAI)	**SSEarly[1] SSLate[2]**		30±1 d SSEarly 45.2±2.6% SSLate 46.8±2.6% 62±1d SSEarly 43.3±2.6% SSLate 44.8±2.7%	[1]SSEarly→ AI between 06:00h-16:00h [2]SSLate→ AI between 16:00h-06:00h [3]ED: Estrus Detection Delaying insemination by approximately 12h did not improve P/AI. AI of heifers should not take place <14h after the onset of estrus.
Mellieon, H. I., et al. (2012)	**5-day CO-Synch + CIDR**		32d. 30.2% 60d. 36.1%	[1]PD: Pregnancy Diagnosis The 7d treatment failed to improve P/AI at 32- or 60-days post AI compared with 5d treatment. Pregnancy per AI was greater for 7d heifers when inseminated after estrus detection. In conclusion, 7d treatment for heifers, when only TAI was employed failed to increase P/AI.
	7-day CO-Synch + CIDR		32d. 26.4-27.9% 60d. 32.3-33.8%	

their beef counterparts mated on the same day (Berry et al., 2020). Moreover, the gestation length of male calf pregnancies was longer than those of female or twin calves (Fouz et al., 2013).

Gestation length of Irish Holstein-Friesian cows was 2.34 to 3.16d longer when mated to Angus, Belgian Blue, or Hereford sires compared to those mated to Holstein-Friesian sires (Fitzgerald et al., 2015). Similarly, Fouz et al. (2013) reported longer gestation lengths of 5.94d in Holstein × Limousin, 5.06d in Holstein × Galician Blonde and 2.32d in Holstein × Belgian Blue crossbreds compared to Holstein × Holstein. According to Foraker et al. (2020b), the gestation length of the second parity cows bred with beef semen (Simmental, Angus, or Simmental × Angus bulls) was 3d greater compared to their first parity and the second parity of cows bred with Holstein semen. The gestation length at first lactation was not affected when high-producing dairy cows inseminated with dairy semen and low-producing dairy cows inseminated with beef semen; however, it was 2d greater for beef-cross-dairy at second calving and 1d higher compared to their first calving. High producing dairy cows received dairy semen had 3 more days open compared to low producing dairy cows that received beef semen (Foraker et al., 2022b).

Calving difficulty

Calving difficulty is an important parameter in dairy cows because, it is related to the production and fertility in the subsequent lactation (Fouz et al., 2013). Although long-term effects of calving difficulty do not affect the performance of the calves, calving difficulty can result in loss of calf, compromised milk production, decreased fertility and health issues of cows (Eaglen et al., 2011; Fouz et al., 2013; Ahmed et al., 2023). In large herds (over 100 cows) minimizing the incidence of calving difficulty contributes to easier and more time-efficient management by reducing the necessity for special care of cows injured during calving. However, the trend of choosing sires with good scores as concerns ease of calving in large herds did not necessarily mirror the PTA for carcass performance (Berry et al., 2020).

Days open were increased by 21.5 days after extremely difficult calving and by 9.2 after a moderate calving compared to the easy calving (McGuirk et al., 2007). Furthermore, difficult calving leads to loss of income, because of added labor, veterinary assistance costs and calf mortality that rises from 2.6% in uneventful calving to 51.8%, in the most difficult calving (McGuirk et al., 2007). Difficult calving in dairy cows, especially in primiparous cows, negatively affects cow's longevity and therefore the investment costs of the herd (de Maturana et al., 2007).

Multiple factors affect calving difficulty in crossbreds; among them, the gestation length, the birth weight of calf, the sex of the calf, twin calving, the age and the parity number of the dam, the maturing of the breed (Mee et al., 2011; Fouz et al., 2013; Berry et al., 2019; Bragg et al., 2021; Coleman et al., 2021; Ahmed et al., 2023; Ask-Gullstrand et al., 2023). Calving difficulty was higher in twin calving, followed by male calving (Fouz et al., 2013). In general, male calves are more prone to calving complications (Mee et al., 2011; Fouz et al., 2013), and more likely to die at or soon after birth. The odds of calving difficulty for dairy cows inseminated with beef semen was 2.2 times higher for male calves compared to female calves. (Berry and Ring, 2024).

Calving difficulty may rise significantly with the increasing parity number of the cow, when inseminated with beef sires (4.11%) in contrast to insemination with dairy sires (1.83%) (Berry et al., 2020; Berry, 2021). Calving difficulty PTA of dairy AI bulls increased from heifers to first-parity cows and to second-parity cows but remained relatively constant thereafter, whereas calving difficulty PTA of beef AI bulls increased consistently from heifers to cows of parity 5 and up (Berry et al., 2020). On the other hand, calving difficulty decreased as the age of the dam increased and it was not related to the type of mating (natural service, AI or ET) (Fouz et al., 2013).

High-reliability sires are needed for use on heifers, irrespective of the breed, dairy or beef sires (Berry et al., 2020). The higher risk of dystocia in younger animals necessitates the use of sires with good rank as concern the ease of calving on heifers (Mee et al., 2011). Most studies agree that calving difficulty is typically more often in late-maturing breeds, due to feto-pelvic incompatibility (Ahmed et al., 2023; Ask-Gullstrand et al., 2023). Higher frequency of calving difficulty was found for beef-cross-dairy breeding with sires of the fast growing, late maturing beef breeds (such as Charolais or Simmental), compared to dairy breeds and the early maturing beef breeds (such as Angus and Hereford); crossbreeding with Limousin was intermediate (Eriksson et al., 2020). In other studies, the highest calving difficulty was noted for Holstein crossbred with Belgian Blue, followed by Limousine (Ahmed et al., 2023) and Galician Blonde compared with purebred Holsteins (Fouz et al., 2013). The ease of calving percentage was 80.3% for Holstein × Holstein, 77.4% for Holstein × Galician Blonde, 76.5 % for Holstein × Limousin and 73.1% for Holstein × Belgian Blue (Fouz et al., 2013). A low incidence of calving difficulty in dairy dams mated by Belgian Blue bulls was reported, maybe because the largest dairy cows in this study were mated with Belgian Blue sires to produce beef-cross-dairy calves (McGuirk et al., 1998).

There is a possibility to identify sires with good genetic merits for both calving ease and carcass weight (Berry et al., 2019). These sires will produce calves that have lighter birth weights and high growth rates, making them desirable for dairy-beef systems, as they will ensure calving success (particularly important in heifers) without compromising meat production (Martín et al., 2020)

Calf mortality and health

Calf health is vital to the value and success of any pre-weaned calf that will be sold (Basiel and Felix, 2022). A genetic variation of calf mortality has been reported, that could be sufficient for the selection in both dairy and beef cattle, and it is expected to have an impact on beef-cross-dairy calves as well (Carlén et al., 2016; Davis et al., 2020). Clasen et al. (2021) confirmed that cow and calf mortality (including stillbirths) decreased when the breeding strategy changed from pure breeding to crossbreeding, both in organic and conventional production systems.

Heritability for calf survival from 1 to 200 days after birth in beef-cross-dairy calves was found low (Davis et al., 2020). The lowest mortality rate of beef-cross-dairy calves from 1 to 200 days was recorded for Belgian Blue-sired calves (8.2%), and the highest for Blonde d'Aquitaine-sired calves (13%); whereas Charolais (9.4%), Simmental (9.5%) and Limousin (12.7%) beef-cross-dairy calves were in between (Davis et al., 2020; Basiel and Felix, 2022). It is common for crossbred calves from dairy herds to be moved to a fattening unit, before the first month of age. Splitting the time after birth into two periods, the survival rate of Holstein × beef calves was 95.7% between 1 and 30 days after birth, 94.7% between 31 and 200 days after birth and 91% between 1-200 days (Davis et al., 2020). As regarding stillbirth rates, crossbreeding between beef bull and dairy dam results in lower frequency of stillbirth than from purebred dairy, except for some crosses with late maturing beef breed sires (Eriksson et al., 2020). The problem of stillbirth events was found to be significantly localized on some farms in Ireland, while most of the farms did not have any problems with stillbirths (Osawe et al., 2021). We could take advantage of the genetic variation about calf mortality between sire breeds to increase the survival rate of the calves and thereby the animal welfare, and to reduce economic loss for the farmers (Davis et al., 2020).

It seems that calf mortality, except for the sire and dam breeds, depends on the sex of the calves, the parity number of the cow and the season they were born. The crossbred male calves present lower survival rate compared to the female calves (Davis et al., 2020). Farmers behavior towards male calves could explain these differences. For example, in North America dairy producers often prioritize female calves care over male calves, because the male ones will not be used as replacement animals (Creutzinger et al., 2021). Furthermore, Canadian dairy farmers reported that male calves had not always received colostrum (9% of farmers) or got their navels dipped in sanitizer (60% of farmers), had not been vaccinated (88% of farmers) and fed less than female calves (83%) (Renaud et al., 2017). The cow parity and the season of calving are also related to calf mortality. It seems that there was a slightly lower survival rate in 1 to 30 days after birth for calves of first parity cows, probably due to increased difficult calving (Davis et al., 2020). Furthermore, higher survival rate was noticed for calves born in the spring, compared to all the other seasons, whereas the lowest survival rates are usually found in the fall and winter months, due to cold and damp weather (Hansen et al., 2003). Increased diarrhea and respiratory issues during the fall, may explain the higher mortality rates in this period (Arens et al., 2023).

Calf respiratory disease, diarrhea, and stayability to 1 year of age are estimated to be poorly heritable (Haagen et al., 2021). It has been suggested that calves may not be able to express genetic health advantages under poor management conditions (Haagen et al. 2021). There are many means of reducing calf mortality in terms of feeding and management, but these improvements only last as long as these conditions are kept at a high level (Davis et al., 2020). Although, improvement of the additive genotype of a calf is permanent, the results are possible only if genetic variation for the traits exists (Hansen et al., 2003).

OTHER INDEXES

Feed intake and growth rates of beef-cross-dairy calves

Growth and feed efficiency in calves are linked; animals with reduced feed intake and normal growth are more feed efficient than those with normal feed intake (Berry, 2021). Other important factors for feed efficiency and calf growth are the quantity and composition of feed, the ability to fulfill the energy demands and the potential to reach harvest weight earlier (reviewed in Berry, 2021). Beef-cross-dairy calves often gained more weight, spent fewer days on feed, and were more efficient than dairy calves, when finished on forage-based diets (Basiel and Felix, 2022).

The average daily gain (ADG) of beef-cross-dairy animals is increased compared to purebred dairy counterparts, although, their daily feed intake seems the same as dairy animals (Berry, 2021; Basiel and Felix 2022). Contrary, beef-cross-dairy calves had 5% less feed conversion and converted less Body Weight into Hot Carcass Weight compared to their beef counterparts (Foraker et al., 2022b).

Milk consumption is an important factor for calves to start growing efficiently. Beef-cross-dairy calves raised in dairy farms were fed less milk and low-quality feed compared with beef-breed calves and tended to have lower growth rates up to 200 days (Martín et al., 2020). Beef-cross-dairy calves that entered the beef system are favored, because weaning occurs at a mean age of 82 days (range 47-119 days), compared to the weaning age of beef calves (approximately 6-7 months old) (Martín et al., 2020). Therefore, lighter or slower-growing beef calves get fed milk for more days to achieve the target weaning weight (Martín et al., 2021). Generally, beef-cross-dairy calves retained on the dairy farm and fattened by the dairy breeder required an average of 2 months more than those bought by the intensive beef fatteners to reach the condition required for slaughter (Bittante et al., 2021).

There are also differences based on the location where the study took place. The crossbred heifers with early maturing beef breed sires had a 7-9% (Swedish) or 10-20% (Finnish) higher gain and those with late maturing beef breed sires had 8-16% (Swedish) or 17-28% (Finnish) higher gain, compared to purebred dairy heifers (Huuskonen et al., 2013b; Eriksson et al., 2020). Young, crossbred bulls from early and late maturing beef breed sires had higher gain (Swedish: 5-7% and 8-15%, Finnish: 7-9% and 13-20%, respectively), than purebred dairy bulls (Huuskonen et al., 2013a, 2014; Eriksson et al., 2020).

The use of genetically superior beef sires on dairy cows could produce beef-cross-dairy calves with increased growth performance for meat production comparable to beef cattle (Martín et al., 2020). Beef-bred cattle have a target slaughter age of 18-22 months (reviewed in Martín et al., 2021), whereas beef-cross-dairy cattle are often slaughtered after 21-22 months to achieve target weights and avoid penalties associated with leanness and conformation (Bown et al., 2016).

Milk yield

Previous studies reported that the sire breed (dairy or beef) had no adverse effect on milk yield (reviewed in Foraker et al., 2022b). However, dairy cows bred with beef sires during their first and second lactations exhibited less total milk yield (up to 1,320 kg), but this is probably because the lowest producing cows were chosen to be inseminated with beef semen (Foraker et al., 2022b). On the other hand, less incidence of mastitis of these cows in their second lactation could be attributed to the lower milk yield (Foraker et al., 2022b). Loss of milk production was noted after extremely difficult calving (Dematawewa and Berger, 1997). A minor reduction in milk yield was also noticed during rotational crossbreeding on Swedish dairy farms, maybe due to the combination of heterosis for milk yield and the larger proportion of older cows in the herd (Clasen et al.,2020). Generally, milk yield was similar between pure-breeding and terminal crossbreeding, and only decreased 1-2% in rotational crossbreeding (Clasen et al., 2020).

DAIRY FARMERS' PREFERENCES FOR BEEF-CROSS-DAIRY BREEDING

Dairy farmers' preferences about phenotypic characteristics of calves and the already applied breeding schemes could be taken into account to set up updated strategies for beef-cross-dairy breeding. Valuable information for the animal breeding chain could also be provided by understanding the dairy farmers' attitude to sire selection depending on the market retail demands as concern meat preferences (Berry and Ring, 2021). The top 3 criteria considered when selecting beef bull semen were cost/AI, conception rate, and calving ease (Halfman and Sterry, 2019).

Beef-cross-dairy calves' phenotypic characteristics

Morphological and behavioral traits of the calves are usually taken into consideration in beef-cross-dairy systems, such as the birth weight of the calf and its effects on carcass, the coat color related to fatteners' preferences, the polledness and docility related to additional costs.

Beef-cross-dairy calf size may be a phenotypic advantage, adding value to pre-weaned calves, because calves are typically sold by weight (Basiel and Felix, 2022). Bull calves are typically sold at a premium price over beef-cross-dairy heifer calves (Basiel and Felix, 2022). Thus, farmers usually prefer for fattening male beef-cross-dairy calves from specific combination of breeds instead of dairy calves.

Coat color is one of the basic characteristics that farmers could gain profit from pre-weaned beef-cross-dairy calves. In the US, the beef producers are often willing to pay a higher price for black colored calves, because they have the potential to qualify for the Certified Angus Beef (CAB) program (Basiel and Felix, 2022). The genetics of cattle coat coloration are well understood, indicated that black coat color being dominant to red (Dorshorst et al., 2015). As such, commercially available semen from many Limousin and Simmental sires are homozygous black (Basiel and Felix, 2022). The white spots on Holsteins are recessive and so Beef-cross-Holstein offspring are typically solid colored, unless the recessive spotting locus inherited from a Simmental sire (Basiel and Felix, 2022).

Polledness is another desirable characteristic that can be beneficial, as dehorning calves creates extra labor, stress during calfhood (Basiel and Felix, 2022) and additional costs, as only the anesthetic cost per calf is estimated about €2.34/ calf (Berry et al., 2019). However, it is possible that increased profit may come from calves with horns or colored hides and not by those traits that are important for farmers (polledness and specific color) (Basiel and Felix, 2022).

Docility in an underestimated parameter that could add economic losses to farmers. Poorly docile animals raise the risk of human injury or death associated with animal attacks (Berry et al., 2019). The additional costs can be divided into 4 categories: labor cost, cost of first aid, cost of treatments and the hospital treatment. The total cost of an on-farm injury calculated about €6,123 (time off work and treatment costs) (Berry et al., 2019).

Applied reproductive management for beef-cross-dairy breeding

Dairy farmers seek for sufficient replacement heifers produced on-farm with dairy semen before using beef semen to maximize the subsequent calf value on the rest of the cows (Berry et al., 2020; Cabrera et al., 2022). Furthermore, it is more likely to breed cows than heifers with beef semen (Berry, 2021; Felix et al., 2023). The 20% of dairy farmers in the USA mentioned that cow parity was taken into consideration when deciding which dairy females will be mated to beef bulls (Halfman and Sterry, 2019). Moreover, cows with reproductive disorders (for example repeat breeder - selected by 74.3% of farmers), worse genetic merit and less milk production (bottom 10-20% of milk produced cows in the herd) are usually selected by farmers for AI with beef semen (Felix et al., 2023). Regarding to breed of beef sire, Angus beef bull semen was selected by the majority (89.7%) of respondents, in the Northeast region of the USA (Felix et al., 2023). Other major breeds as ranked by respondents were Limousin (11.2%), Simmental (9.4%), Hereford (7.7%), and Charolais (5.3%), whereas a total of 10.5% of respondents use other breeds in their operations (Felix et al., 2023). Large farms (> 100 cows) were more likely to use Limousin, Simmental, and Charolais bulls than smaller farms (< 100 cows). Respondents who were using multiple beef breeds were more likely to report profit up to $100 per calf sold, than those who indicated the use of just one beef breed (Felix et al., 2023).

An increased percentage (64.1%) of dairy farmers reported that they are selling beef-cross-dairy calves before 1 week of age; a few farmers are selling them between 1 and 4 weeks of age (2.5%), at weaning (5.1%) or after weaning (6.9%), and some of them finishing calves for slaughter (10.9%). Selling calves before 1 week of age were less likely to gain a profit of $100 or more per animal compared with those respondents who reported other ages of sale (Felix et al., 2023).

The current use of beef semen in the Northeast region of the USA is 76.4% at dairy farms, whereas the 4.7% of dairy farmers are planning to use beef semen in their herds in the future; as this procedure was noted profitable by a large rate of the Northeast USA farmers (Felix et al., 2023). In Sweden, farmers indicated sexed semen and beef semen as the two most used breeding tools, especially farmers younger than 50 years old (Clasen et al., 2021). Beef semen had high approval among all respondents as a good breeding tool, especially in large farms (>100 dairy cows) and those farms that consult advisors (Clasen et al., 2021). Combinations including both sexed semen and beef semen were generally ranked high by farmers. Swedish farmers agreed that beef-cross-dairy calves increase the income of the farmer and that the knowledge about beef-cross-dairy breeding is sufficient to make it a safe choice (Clasen et al., 2021). Most of the respondents disagreed with the statement that calving difficulty was increased by the use of beef semen (Clasen et al., 2021).

CONCLUDING REMARKS

Beef × Dairy crossbreeding is used worldwide the last decades. This breeding strategy could give great advantages to increase beef production by using less cows as dams. Although the percentage of replacement heifers depends on many factors, there are still enough dairy cows that could be used for crossbreeding to increase the production of calves for fattening, especially in countries that are deficient in meat production. The information presented in this review leads to the assumption that, there are not enough research data on specific synchronization protocols for Artificial Insemination with beef or sexed-beef semen in dairy cows.

Another important issue that needs further investigation is the preferences of farmers, consumers, and the market demand in each country separately, to select and propose the best choices in each case. Strategies on reproductive management must be drawn up and further research is needed on specific estrous synchronization protocol for AI of dairy cows / heifers with beef and sexed-beef semen. The dissemination of these strategies to farmers is also an important issue.

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CONFLICT OF INTEREST

None declared

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