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PAPER



Veal and beef meat quality of crossbred calves from dairy herds using sexed semen and semen from double-muscled sires

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ABSTRACT

The use of sexed semen to produce replacement heifers in dairy farms allows many cows to be inseminated with bulls of beef breeds with the aim of improving meat production. The major dairy and beef breeds are undergoing rapid genetic improvement as a result of more efficient selection methods, necessitating evaluation of the quality of meat produced by beef × dairy crosses obtained using current genetics. As part of a larger project, we carried out quantitative and qualitative evaluations of the veal and beef produced from crossbred calves produced by dairy farms that use sexed semen to obtain purebred replacement heifers. A total of 231 bull-calves were reared in the dairy farms or in specialised fattening farms, slaughtered, and sampled for meat quality analysis. These comprised: 104 crossbred calves, mainly from Belgian Blue sires and Holstein dams, which were intensively fattened for veal production; 84 beef × dairy crossbred calves, destined for beef production on the dairy farm of origin (12 calves) or in a specialised intensive fattening centre (72 calves); 26 purebred Charolais and 17 beef crosses from suckler cows, included for comparison, which were fattened in the same fattening centre and fed the same diet as the beef × dairy crosses. Veal and beef meat differed in all quality traits; the beef produced by dairy farmers was better than the beef produced by specialised fatteners in terms of cooking losses and tenderness, even though these animals were much older and weighed less at slaughter. There were minor differences in the quality traits of veal between the various beef × dairy breed combinations. In the case of intensive beef production, minor differences were observed between Belgian Blue-sired crosses from Brown Swiss cows (lipid content and shear force of meat) and Belgian Blue-sired crosses from crossbred cows (haem iron, lightness, yellowness, and hue) in comparison with crosses from Holstein cows. The beef of young bulls from suckler cows (Charolais and crosses) had a lower pH, dry matter and lipid contents, slightly higher cholesterol and haem iron contents, and higher cooking losses than meat from beef × dairy crosses. Taking into account the results from the entire project, we conclude that the combined use of sexed semen for pure-breeding and conventional beef semen for terminal crossbreeding improves meat production from dairy herds, both quantitatively and qualitatively.

HIGHLIGHTS

- The meat from beef × dairy crossbred calves was found to have valuable qualitative characteristics.
- With regard to veal production, the meat quality characteristics of crossbred calves did not differ appreciably between breed combinations.
- With regard to intensive beef production, the meat from beef × dairy young bulls had greater quality than that from suckler cows.
- Crosses fattened by dairy farmers grew slower than those by specialised fatteners, but their beef was better in terms of cooking losses and tenderness.

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Introduction

With the intensification of dairy production, the practice of mating dairy cows to beef bulls to obtain crossbred calves for fattening and slaughter has almost disappeared. The main reasons for this are the reduced

fertility and longevity of dairy cows, increasing their turnover rate, and the need to use almost all the cows to produce purebred replacement heifers (Berry 2021). In intensive dairy systems, there has been a constant decline in the number of calves from dairy herds

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available for meat production, managed through either on-farm or off-farm fattening, although numbers have remained robust in pasture-based and mountain systems (McHugh et al. 2010). Moreover, the genetic improvement of dairy characteristics (Berry 2021) has resulted in a worsening of their average 'meat' attitude, which comes increasingly only from purebred dairy bull-calves. The purebred and crossbred calves from dairy farms in Europe are mainly destined for veal production (European Commission Agri 2011). Lastly, the number of male purebred dairy calves is also decreasing because genetic and phenotypic improvement in milk production is decreasing the number of dairy cows needed for producing the milk required by local markets.

A recent important change has been the use of sexed semen to obtain replacement heifer calves (Cottle et al. 2018). Initially, this technique was used mainly to mitigate the effects of reduced fertility and longevity (VanRaden et al. 2004) but is now also used to increase the proportion of cows over and above replacement needs leaving the excess for crossbreeding in order to increase meat production from dairy herds (Ettema et al. 2017). Several recent scientific articles have studied the effects of sexed semen on the reproductive efficiency of cows (Holden and Butler 2018), genetic trends in dairy populations (Bérodier et al. 2019), the types of semen used for beef crossbreeding (Berry 2021), and the economics of crossbred calf production (Butler et al. 2014; Ettema et al. 2017). Few studies have dealt with the characteristics of the resulting crossbred calves. A large field study (MeetBULL project) was carried out in the Veneto region (northeastern Italy) with the aim of analysing the effects of using sexed semen on the reproductive efficiency of dairy farms and the value of the meat from crossbred calves in different meat-production systems. From our analysis of the output of 50,785 inseminations of 15,580 cows from 106 dairy farms, we confirmed that sexed semen was effective in modifying the sex ratio, and did not significantly reduce the conception rate of the cows, especially the heifers (Bittante et al. 2020a). On the other side, crossbreeding with beef bulls increased fertility of dairy cows, so the combined use of dairy sexed semen and conventional beef semen had an overall null or positive effect on the reproductive efficiency of the dairy farm. The price of 1285 beef \times dairy crossbred calves (at about one month of age) was approximately three times the price of the purebred dairy calves, and even 4 times in the case of Belgian Blue-sired crossbred calves (Bittante et al. 2020b), increasing the dairy farmers' income respect to the use of purebred mating. Only

about one-sixth (16%) of the crossbred calves were retained by dairy farmers for on-farm beef production, mainly for the needs of the farmers' families or to supply local butchers and private buyers. All the other calves were sold to specialised intensive fatteners producing veal (55% of calves) or beef (28%). The carcasses produced by the veal fatteners weighed about half those produced by the specialised beef fatteners and in less than half the time, so the veal crossbred calves had the highest average growth rate from birth, and also the highest dressing percentage (Bittante et al. 2021). On-farm fattened crossbred calves took longer to reach a carcass weight similar to the calves intensively fattened by beef producers, and had a similar dressing percentage but a lower muscularity score.

There is little recent information available on the quality traits of meat produced by beef \times dairy crossbred calves; any results obtained in the past would relate to beef and dairy breeds much less genetically improved than modern breeds. Moreover, while veal producers prefer using beef \times dairy crossbred calves, specialised beef fatteners use almost exclusively yearlings from purebred beef breeds and crosses obtained from suckler cows (Gallo et al. 2014). This is possibly because in the past dairy and beef \times dairy calves were considered too early maturing and less performing for beef production.

This part of the MeetBULL project is therefore aimed mainly at comparing the performances and quality traits of (i) meat obtained from beef \times dairy crossbred calves in different farming systems (dairy farms, intensive veal producers, and intensive beef producers); (ii) veal obtained from the major breed combinations of crossbred calves; (iii) beef obtained from beef \times dairy crossbred calves compared with purebred (Charolais) and crossbred yearlings from suckler cows; (iv) beef obtained from the major breed combinations of crossbred calves.

Materials and methods

This study is based on meat samples taken from commercial slaughterhouses on the carcasses of animals reared in dairy farms and intensive specialised veal and beef fatteners following the commercial practices and according the norms on welfare of animals set by European Union. So no institutional animal care and use committee approval of animal procedures were required.

Experimental design, animals, and farms

Previously published articles from the meetBULL project have reported information on the dairy farms

involved in the project, and the results of inseminations with sexed and beef semen (Bittante et al. 2020a), the commercial value of the newborn crossbred calves produced (Bittante et al. 2020b), and the performances of the crossbred calves fattened on the dairy farm of origin (12 farms, 245 calves) or sold to specialised veal (22 farms, 847 calves) or beef (19 farms, 438 calves) fatteners (Bittante et al. 2021). To characterise the quality traits of the meat produced by the beef \times dairy crossbred calves, we selected three batches of calves, one from the largest farm of each of the three meat production systems. A total of 231 calves were monitored and sampled after slaughter:

- 12 beef \times dairy crossbred calves reared and fattened on the dairy farm where they were born;
- 104 beef \times dairy crossbred calves intensively fattened for veal;
- 72 beef \times dairy crossbred calves intensively fattened for beef;
- 26 purebred Charolais and 17 crossbred yearlings from suckler cows of mixed beef breeds reared for beef.

The 43 young bulls in the last category did not originate from dairy farms (the Charolais were imported from France, the beef crosses from Sicily), but were included in the trial as reference animals for the intensive fatteners in the area. These two 'reference' batches and the batch of 72 beef \times dairy crosses for beef production were all fattened over the same period, in the same barn (although in different pens), and fed the same total mixed rations. The operational conditions of the specialised beef fatteners in the region are described in previous studies (Gallo et al. 2014). The number of calves of the first group was small (12 calves) because dairy farmers form batches use only calves born in their farm during the year. For this reason, we excluded the purebred dairy calves.

The genetic groups of the calves are described according to their sire and dam breeds (BB = Belgian Blue; HF = Holstein Friesian; BS = Brown Swiss; CB = Crossbred dairy cows; CH = Charolais; DairyC = other beef \times dairy crosses; BeefC = mixed breed crosses from suckler cows) as follows:

- Dairy farmers producing beef: one group comprising exclusively crossbred calves (12 heads: 5 BB \times HF and 7 DairyC);
- Veal fatteners: four genetic groups of crossbred calves (50 BB \times HF; 18 BB \times BS; 24 BB \times CB; 12 DairyC);

- Beef fatteners: six genetic groups (47 BB \times HF; 6 BB \times BS; 10 BB \times CB; 9 DairyC; 26 CH \times CH; 17 BeefC).

The dairy farm involved in the trial (Società Agricola Donadel e Marangon, *via del Molino 25*, Campocroce di Mogliano Veneto, Italy; <https://cadonadel.it/>) is a family-operated enterprise rearing dairy cows, rearing, and fattening crossbred calves, and producing artisanal cheeses. The cows are artificially inseminated with sexed dairy semen to produce replacement heifers, and with beef bull semen to obtain crossbred calves. Dairy and beef products are sold directly to consumers. The farm is registered for milk recording with the Veneto Regional Breeders' Association (ARAV; Associazione Regionale Allevatori del Veneto, Vicenza, Italy).

The specialised veal fattening company involved in the trial [Colomberotto S.p.A., *via Montegrappa 68/72*, 31010 Moriago della Battaglia (TV), Italy; <https://www.colomberotto.it/wordpress/>] operates several fattening centres for veal and beef production, and also slaughters the animals, dissects the carcasses, and sells some of the meat directly to consumers. The company is a member of the Association of Bovine Meat Producers of the Veneto [Associazione Produttori Carni Bovine del Veneto, Legnaro (PD), Italy; <http://www.unicarve.it/>].

The specialised beef fattening company [Stalla Sociale Monastier, *via Giacomelli 9*, 31050 Monastier (TV), Italy; <http://www.stallasocialemonastier.it/it/home/>] is a cooperative operation and member of AZOVE—Beef Producers Organisation [Organizzazione Produttori Carni Bovine, *via del Macello 9*, 35013 Cittadella (PD), Italy, <http://www.azove.it/>], which takes care of slaughter, carcass dissection, and marketing.

Slaughter data and meat sampling

Immediately before slaughter, the following data were obtained for each calf: date of slaughter, dairy farm of origin and fattening farm, ID code, live weight (measured with computer-controlled scales that were calibrated before every slaughter session). Average daily gain from birth was simply calculated as the ratio between liveweight at slaughter and slaughter age. At the end of the slaughter-line, the carcasses were identified, automatically weighed, and classified for carcass muscularity on the SEUROP scale (Commission-of-the-European Communities 1982). The scale has six classes from S (superior: all muscle profiles extremely convex) to P (poor: all profiles concave to very concave), each of which we divided into three sub-classes to increase

discrimination, designated +, =, or -. These were then transformed into numerical scores ranging from $p = 1.00$ to $S = 6.00$, adding 0.33 for the + sub-classes and subtracting 0.33 for the - sub-classes.

The day after slaughter and shortly after dividing the carcass sides into quarters (pistol cuts), a sample rib cut was taken from the left carcass side at the level of 5th rib (in accordance with European Commission Regulation (EC) No. 1249/2008, European Economic Community Regulation (EEC) No. 1208/81). Animals with incomplete information, or that were sick or injured were not sampled. The rib cuts were cooled, vacuum packed, and labelled, then taken to the meat laboratory of DAFNAE, University of Padova, Italy, for analysis.

Meat quality analysis

The meat analyses are described in detail in a previous study (Patel et al. 2019). Briefly, after 7 days ageing at 4°C, the pH of the *Longissimus thoracis* samples was measured at three different points with a Delta Ohm HI-8314 pH metre, and subsequent analyses were carried out on the average of these three measures. The meat samples were then cut perpendicularly to the muscle fibres, and 1 h later the colour of the muscle surface was measured at five different points with a Minolta CM-508c (illuminate: D65, observer: 100) according to the procedure described by Schiavon et al. (2011) and Savoia et al. (2019b). The mean colour from these five points was expressed in CIE-lab values, where L^* represents the lightness of meat (on a scale from 0 = black to 100 = white), a^* and b^* represent the redness and yellowness colour axes (Cartesian rectangular coordinates of the sample in the colour plane), C^* and h^* represent the chroma and the hue (polar coordinates of the sample in the colour plane), where C^* ($C^* = (a^{*2} + b^{*2})^{0.5}$) is the radial distance between the point representing the sample and the pole (equivalent to the origin of the Cartesian rectangular coordinates), and h^* ($h^* = \tan^{-1} (b^*/a^*)$) is the polar angle or azimuth indicating the direction of the sample colour point between a^* and b^* axes (CIE 1977). To measure cooking losses, a 2-cm-thick meat steak was placed in a polyethylene bag and cooked in a water bath at 70°C for 40 min: cooking loss was calculated as the percentage difference between the weight of the meat before and after cooking. The texture of the cooked meat sample was measured by shear force using a TA-HDi Texture Analyser (Stable Micro Systems, Godalming, United Kingdom) fitted with a Warner Bratzler shear attachment (10 N load cell,

crosshead speed of 2 mm/s); the average of three measurements was analysed with the Texture Expert software (Joseph 1979).

Chemical analysis of the meat was carried out according to the AOAC methods. Ash content was measured after drying the meat at 525°C (AOAC 2000), protein was analysed by the Kjeldahl method, dry matter by oven drying, and the lipid percentage was determined by the extraction method using petroleum ether (AOAC 2016). Cholesterol content was measured by extraction by saponification of ground freeze-dried meat sample following the method described by Fletouris et al. (1998) modified by extending the length of saponification to 30 min. This method was used on meat samples also by other authors (Jerez-Timaure et al. 2021; Pretorius and Schönfeldt 2021). Haem iron was analysed according to Hornsey (1956) modified by Lombardi-Boccia et al. (2002a, 2002b).

Statistical analysis

Data editing

A preliminary analysis was carried out with the model described below, and all data with a residual value outside the residual standard deviation (RSD) interval 0.00 ± 3.00 were considered outliers and excluded (0.0–1.8% of data according to trait).

Statistical model

All data were analysed using the SAS MIXED procedure (SAS Institute Inc., Cary, NC, USA) according to the following linear model:

$$y_{ijk} = \mu + \text{MeatSystem}_i + \text{BreedCombination}_j(\text{MeatSystem}_i) + e_{ijk}$$

where y_{ijk} is the trait analysed; μ is the overall intercept of the model; MeatSystem_i is the fixed effect of the i th production system ($i = 1$ for calves retained, weaned, and fattened by the dairy farmers to produce beef; $i = 2$ for calves bought by specialised fatteners to produce veal; $i = 3$ for calves bought, weaned and reared by specialised fatteners to produce beef); $\text{BreedCombination}_j(\text{MeatSystem}_i)$ is the fixed effect of the genetic group of calves within production system ($j = 1$ –11) as previously defined; e_{ijk} is the random residual $\sim N(0, \sigma_e^2)$. Considering the hierarchical structure of the data, the effect of MeatSystem_i was tested on the error line of $\text{BreedCombination}_j(\text{MeatSystem}_i)$.

The significance level ($p < 0.05$) of the differences among calves of the various beef \times dairy breed combinations obtained in the project within veal and beef

intensive fattening systems was based on comparisons between the BB × HF calves, taken as the reference, and the other breed combinations (BB × BS, BB × CB, and DairyC). In the case of specialised intensive beef producers, comparisons were also made between the 4 beef × dairy genetic groups vs. the two genetic groups of yearlings obtained from suckler cows, and between the purebred CH × CH vs. BeefC.

Results and discussion

Effects of farming system on the meat quality of crossbred calves for veal and beef production

Over the entire survey, slightly more than half the crossbred calves were sold to specialised calf fatteners for white meat (veal) production. The others were destined for red meat (beef) production (Bittante et al. 2021), a third of them retained, weaned, and fattened on the dairy farms where they were born, and two thirds sold to specialised beef fatteners.

The specific interest of this study was not on performance, but on meat quality, although the performances of the batches of animals in this study were analysed to assess how well they represented the three beef farming systems investigated in the entire survey. Some differences in the average performances were found between the calves from the three

farming systems in the entire survey and the calves of the three batches used in this study. The calves reared by the two leading intensive veal and beef fatteners had a lower average age at slaughter, and greater live-weight and carcass weight, indicating their greater growth rate from birth to slaughter (Table 1). In some way, these represent the performances obtainable under optimum production conditions and could serve as a future target for the two intensive farming systems. The growth rate of the calves reared on the dairy farm of birth in this study was very similar to that in the entire survey. The dressing percentages and muscularity scores of the three batches (Table 1) did not differ much from the average value for the corresponding farming system in the entire survey (Bittante et al. 2021).

The beef × dairy crossbred calves in this study proved able to achieve a very high growth rate from birth when destined for veal production (Table 1). The level of muscularity at slaughter reached an average value intermediate between R and U on the European Union's official scale (Commission-of-the-European Communities 1982). These two values correspond approximately to those achieved by purebred, dual-purpose, and conventional (non-double-muscling) beef young cattle, respectively (Albertí et al. 2008). The values obtained in this study are similar to or higher

Table 1. Least squares means of production systems on the performance and meat quality traits of calves obtained by dairy farms using sexed semen to produce purebred replacement heifers and beef semen to produce beef × dairy crossbred calves, and subsequently retained for fattening on the dairy farm (Breeder) or sold to specialised intensive veal and beef fatteners.

	Meat system			Contrast (p-value)		RMSE
	Fattener veal	Fattener beef	Breeder beef	Veal vs. beef	Beef-fatt. vs. beef-breed.	
Calves, N	104.00	115.00	12.00	–	–	–
Growth traits						
Age at slaughter, d	207.00	476.00	637.00	<0.001	<0.001	32.00
Slaughter weight, kg	308.00	665.00	624.00	<0.001	0.005	44.00
Daily gain, kg/d	1.49	1.40	0.98	<0.001	<0.001	0.13
Carcass traits						
Carcass weight, kg	181.00	404.00	347.00	<0.001	<0.001	31.00
Dressing, %	58.97	59.50	54.44	0.017	<0.001	4.16
SEUROP, score	3.58	3.19	2.67	0.008	n.s.	0.64
Meat composition						
Dry matter, %	25.20	27.40	27.60	<0.001	n.s.	1.30
Crude protein, %	20.90	22.00	22.00	<0.001	n.s.	0.70
Ether extract, %	2.20	3.46	3.61	<0.001	n.s.	1.23
Ashes, %	1.09	1.10	1.01	0.003	0.001	0.06
Meat quality						
pH	5.60	5.55	5.59	0.195	n.s.	0.12
Cholesterol, mg/100 g	59.20	43.70	41.10	<0.001	n.s.	4.30
Haem iron, mg/kg	6.00	16.20	15.50	<0.001	n.s.	2.00
Cooking losses, %	31.70	35.10	33.60	<0.001	0.022	2.10
Shear force, N/cm ²	22.00	28.90	22.20	0.006	0.002	6.50
Meat colour traits						
Lightness, L*	47.40	40.40	40.60	<0.001	n.s.	2.40
Redness index, a*	7.80	14.60	14.40	<0.001	n.s.	1.60
Yellowness index, b*	14.00	11.90	12.40	<0.001	n.s.	1.20
Chroma (saturation), C*	16.10	18.80	19.00	<0.001	n.s.	1.70
Hue angle, H*	60.80	39.40	40.60	<0.001	n.s.	3.70

SEUROP score: muscularity score according to European Union (S = superior, score 6.0 to P = poor, score 1.00); RMSE: root mean square error.

than those found for veal calves reared in specialised farms in other western European countries (Klont et al. 1999; Alberti et al. 2005).

The batches for specialised beef production varied little in their performances according to farming system. The performances of the dairy crossbred calves fattened by specialised beef producers were very similar to the average performances of purebred yearlings of conventional beef breeds and beef crosses obtained from suckler cows (Xiccato et al. 2005). The average growth rate from birth and muscularity scores were slightly lower than those of veal calves (Table 1), but the slaughter liveweight and carcass weight were more than double. As already seen, crossbred calves fattened by the dairy breeders did not perform as well as those fattened on a specialised farm (Table 1). In another study (Savoia et al. 2019b)—although with a different breed (double-muscled Piemontese young bulls) and in a different environment—we found that the carcasses of calves fattened on the farm of birth by breeders (in this case, suckler cow breeders) weighed less, despite being older at slaughter, and were less muscular than the carcasses of calves fattened by specialised beef producers, although the differences were smaller than in the present study on beef \times dairy crossbred calves.

It is worth noting that there were significant differences between veal and beef in all the quality traits, except pH (Table 1). Regarding composition, veal was characterised by lower contents of dry matter, protein, fat, and minerals than beef. Of the chemical compounds measured, only cholesterol had a higher content in veal than in beef. It is worth noting that, in a previous study on meat quality of young bulls belonging to Italian beef breeds (Patel et al. 2021), and using the same method used here, the cholesterol content of beef was intermediate between that found here on beef and veal meat samples. The physical/technological traits of meat (cooking losses and shear force of cooked meat) were both lower (more favourable) in veal than in beef meat samples. As expected, the haem iron content of veal was less than half that of beef (Table 1) and was obviously the main reason for the difference in meat colour: veal had greater lightness, yellowness and hue, and less redness and chroma (Table 1).

Moving on to the effects of the two farming systems producing beef meat, in contrast to the large differences in the animals' performances, meat quality was minimally affected (Table 1), the only differences being in favour of the beef produced by dairy farmers that had lower cooking losses and shear force (and also ash content). In the study on Piemontese young bulls, farming system had even smaller effects on quality traits than in

the present study: the only significant difference was in favour of traditional rearing by cow breeders and regarded the lightness of the meat (Savoia et al. 2019b).

Effects of breed combination on the meat quality of crossbred beef \times dairy calves destined for intensive veal production

Veal production has undergone profound changes over the last two decades, and most of the published research on veal quality regards production systems that no longer exist: individual housing, liquid-only diets, use of growth promoters, very young/lightweight end-point, etc. Ngapo and Garièpy's (2006) review article on the factors affecting the quality of veal meat clearly illustrates the conditions that early research dealt with. Welfare regulations stipulating group rearing and the availability of solid feedstuffs in response to legal restrictions on and consumer aversion to the use of growth promoters, and to the increase the age and weight of animals at slaughter have considerably changed the characteristics of the animals. But, there is a lack of information on veal production in this new scenario, particularly in relation to the quality traits of veal and the effects of calf breed or breed combination.

We took the crossbred calves from double-muscled Belgian Blue sires and Holstein Friesian cows (BB \times HF) as the reference, as this is the type most commonly used for veal production in several European countries. There were modest differences between veal calves from the HF and other dams. The only difference in the meat of calves from Brown Swiss cows (BB \times BS) was a slightly greater cooking loss than BB \times HF (Table 2). The calves from crossbred dairy cows (BB \times CB) performed better than the reference BB \times HF calves (higher daily gain, dressing percentage, and carcass muscularity score), but the meat quality was similar (only the cholesterol content of the rib-eye meat sample was slightly higher). Regarding the other breed combinations (DairyC, mainly from Limousin and Simmental breeds), the only differences were their higher daily growth and the greater shear force (lower tenderness) of the rib-eye cooked meat samples (Table 2).

In a study by Steinwider et al. (2001), Simmental calves, at an average carcass weight much lower than in the present study, had a higher growth rate and dressing percentage than Holstein and Brown Swiss purebreds, but the meat samples were darker. Dutch veal calves investigated by Klont et al. (1999) had a slightly lower average carcass weight than in the present study, but the meat had very similar pH and lightness, and a much higher redness index; in the

Table 2. Least square means of the performance and meat quality of calves obtained by dairy farms using sexed semen to produce purebred replacement heifers and beef semen to produce beef \times dairy crossbred calves reared by a specialised veal fattener.

	BB \times HF	BB \times BS ^a	BB \times CB ^b	Dairy ^c
Calves, N	50.00	18.00	24.00	12.00
Growth traits				
Age at slaughter, d	214.00	208.00	207.00	198.00
Slaughter weight, kg	307.00	305.00	310.00	308.00
Daily gain, kg/d	1.44	1.46	1.51*	1.54*
Carcass traits				
Carcass weight, kg	180.00	183.00	186.00	174.00
Dressing, %	58.41	60.16	61.20**	56.12
SEUROP, score	3.34	3.46	3.93**	3.58
Meat composition				
Dry matter, %	25.00	25.30	25.10	25.20
Crude protein, %	20.80	21.00	21.10	20.70
Ether extract, %	2.18	2.31	1.97	2.34
Ashes, %	1.09	1.08	1.10	1.09
Meat quality				
pH	5.64	5.59	5.59	5.59
Cholesterol, mg/100 g	58.30	58.70	60.60*	59.00
Haem iron, mg/kg	6.10	6.40	5.50	6.10
Cooking losses, %	31.00	32.30*	31.90	31.60
Shear force, N/cm ²	20.00	21.80	22.20	24.20*
Meat colour traits				
Lightness, L*	47.70	46.80	48.50	46.60
Redness index, a*	7.70	8.00	7.40	8.20
Yellowness index, b*	14.00	13.60	14.10	14.20
Chroma (saturation), C*	16.20	15.90	15.90	16.50
Hue angle, H*	61.10	59.80	62.40	60.10

BB: Belgian Blue sire; HF: Holstein-Friesian dam, BS: Brown Swiss dam; CB: dairy crossbred dam.

* $p < 0.05$; ** $p < 0.01$; .

^aAsterisks refer to the contrast between BB \times BS and BB \times HF.

^bAsterisks refer to the contrast between BB \times CB and BB \times HF.

^cAsterisks refer to the contrast between other crosses and BB \times HF.

same study, Meuse-Rhine-Yssel purebred calves yielded heavier carcasses than purebred Dutch Friesian calves, although the meat quality traits were similar. Veal meat samples from purebred Limousin and Tudanca \times Charolais calves reared outdoors as suckling calves and slaughtered at a comparable weight to the calves in the present study had a similar chemical composition and lightness, but higher redness and lower yellowness indices (Aldai et al. 2012); Limousin veal had greater lightness and smaller amounts of lipids than Tudanca \times Charolais veal. Colour and fatness are the major concerns of veal consumers, but breeds of local origin are positive factors in their 'willingness to pay more' (Resano et al. 2018).

Comparison between the meat quality of beef calves and crossbred beef \times dairy calves destined for intensive beef production

In the case of beef production, more information is available on the effects of breed or breed combination on meat quality traits. The Veneto Region has the highest concentration of specialised fattening farms in

Europe (European Commission Agri 2011). Stock calves for beef production are mainly imported pure beef breeds, the majority of which are French Charolais yearlings, although calves of Limousin and French local breeds (Salers, Aubrac) are also imported (Gallo et al. 2014). Crossbred calves, imported as yearlings mainly from France and Ireland, account for a smaller proportion of fattening calves. The French crosses are often obtained from Charolais bulls mated to local suckler cows (Salers, Aubrac, Gasconne, etc.), while the Irish crosses imported into Italy are often obtained from continental beef bulls (Belgian Blue and Charolais) and dairy or suckler cows (Cafferky et al. 2019). Recently, specialised fatteners have also bought crossbred calves from Southern Italian regions, obtained mainly from Charolais bulls mated to local or crossbred suckler cows. This state of affairs is the reason why we included purebred French Charolais and crosses from Sicilian suckler cows in this study as references for comparisons with the beef \times dairy crosses produced by dairy farms using sexed semen to obtain replacement heifers.

The young bulls of different breed combinations were fattened in the same barn and fed the same fattening diet. The beef \times dairy crosses reached commercial maturity slightly earlier and at a lower slaughter weight than purebred and crossbred beef animals (Table 3). On average, the calves from dairy herds had a lower growth rate from birth (about 0.1 kg/d) than the calves from beef herds, although it should be borne in mind that the former were artificially fed with milk replacer and weaned much earlier than the calves suckling their mother's milk *ad libitum*. The carcasses of calves from dairy cows had slightly lower muscularity scores, but there was no difference in the dressing percentages (Table 3). The composition of the meat of calves from dairy cows was characterised by a higher dry matter content—having more lipids—than the meat from the progeny of suckler cows, which could explain the lower cooking losses of the former. There were only non-significant differences in terms of meat shear force and colour traits, although the meat from beef \times dairy crosses had a slightly lower haem iron content and greater pH (Table 3), as well as a slightly lower average cholesterol content. Overall, the differences observed in the quality of beef from dairy and suckler cows seems not much relevant in relation to the market needs.

Several differences between the two groups of genotypes obtained from suckler cows were also evident. The crossbred calves from suckler cows performed less well than the purebred Charolais, but they differed

Table 3. Least square means of the performance and meat quality of calves obtained by dairy farms using sexed semen to produce purebred replacement heifers, and beef semen to produce beef × dairy crossbred calves in comparison with calves obtained from suckler cows, all reared by a specialized beef fattener.

	Suckler cows		<i>p</i> ^a	Dairy cows			
	CH × CH	BeefC ^b		BB × HF	BB × BS ^c	BB × CB ^d	DairyC ^e
Calves, <i>N</i>	26.00	17.00		47.00	6.00	10.00	9.00
Growth traits							
Age at slaughter, d	497.00	476.00*	*	486.00	477.00	466.00	479.00
Slaughter weight, kg	723.00	676.00**	***	641.00	659.00	641.00	632.00
Daily gain, kg/d	1.46	1.47	*	1.32	1.39	1.37	1.31
Carcase traits							
Carcase weight, kg	444.00	407.00***	***	389.00	395.00	383.00	388.00
Dressing, %	60.24	59.00	—	59.52	58.81	58.64	60.24
SEUROF, score	3.71	3.16***	**	3.11	3.11	2.97	3.08
Meat composition							
Dry matter, %	26.90	26.10	*	27.40	28.30	27.60	27.60
Crude protein, %	22.20	22.00	—	22.10	22.10	22.20	21.70
Ether extract, %	2.73	2.15	***	3.19	4.32*	3.48	4.12
Ashes, %	1.12	1.09	—	1.12	1.07	1.09	1.10
Meat quality							
pH	5.53	5.52	***	5.58	5.65	5.59	5.59
Cholesterol, mg/100 g	46.70	42.50**	**	43.20	44.20	42.00	43.80
Haem iron, mg/kg	14.70	17.20***	***	17.10	15.70	15.70*	15.80
Cooking losses, %	36.90	35.30*	*	35.80	32.50***	34.80	35.00
Shear force, N/cm ²	29.70	29.30	—	28.50	26.70	29.00	29.20
Meat colour traits							
Lightness, <i>L</i> *	41.30	40.30	—	39.30	41.60*	41.00*	41.50
Redness index, <i>a</i> *	13.90	16.00***	—	14.50	13.80	14.70	14.10
Yellowness index, <i>b</i> *	11.70	12.40	—	11.40	11.90	12.80**	11.90
Chroma (saturation), <i>C</i> *	18.20	20.10***	—	18.50	18.30	19.50	18.50
Hue angle, <i>H</i> *	40.10	38.50	—	38.00	40.30	40.90*	40.20

CH × CH: purebred Charolais calves; BeefC: mixed breed crosses from suckler cows; BB: Belgian Blue sire; HF: Holstein-Friesian dam; BS: Brown Swiss dam; CB: dairy crossbred dam; DairyC: other beef × dairy crossbred calves.

^a*p*-Value (asterisks) refers to the significance of the orthogonal comparison between young bulls obtained from suckler cows (Charolais purebreds and mixed crosses) vs. crosses obtained from dairy cows in farms using sexed semen for production of purebred dairy replacement heifers and beef semen for crossbreeding of cows exceeding replacement needs.

^bAsterisks refer to the contrast between mixed crossbred calves from suckler cows and purebred Charolais young bulls.

^cAsterisks refer to the contrast between BB × BS and BB × HF.

^dAsterisks refer to the contrast between BB × CB and BB × HF.

^eAsterisks refer to the contrast between the crossbred calves of the previous three columns and other types of crosses, always obtained from dairy cows.

p* < 0.05; *p* < 0.01; ****p* < 0.001.

little, both quantitatively and qualitatively, from the crossbred calves from dairy cows (Table 3).

Beef breeds—as well as dairy breeds—are undergoing genetic changes as a result of new advances in selection methods. This is particularly true for growth rate and carcase characteristics, but much less so for meat quality traits, which are not yet included in selection indices (Przybylski and Hopkins 2014; Berry et al. 2019), despite being heritable (Johnston et al. 2003; Mortimer and Przybylski 2016; Farmer and Farrell 2018) and (some of them) responsive to selection based on prediction from near-infrared spectra (Cecchinato et al. 2011; Savoia et al. 2019a, 2021). The genetic evolution of meat quality traits has, therefore, been modest and is dependent on correlations with other traits included in the selection indices. The meat quality of beef breeds was found to correlate moderately (Boukha et al. 2011; Savoia et al. 2019a) or barely (Gill et al. 2010) with growth rate and carcase traits, but these authors are unaware of any similar information with regard to dairy breeds.

Effects of breed combination on the meat quality of crossbred beef × dairy calves destined for intensive beef production

The four breed combinations obtained from dairy farms were similar to each other in terms of meat quality. The only significant differences with respect to the BB × HF young bulls were: greater lipid contents, lower cooking losses, and lighter coloured meat from BB × BS crosses; and a lower haem iron content, and lower lightness of colour and greater yellowness and hue indices in meat from BB × CB crosses (Table 3). The other crossbred calves (DairyC) exhibited no differences. So the beef quality of crosses obtained from cows different from HF tended to be favourable, but their market value seems moderate.

The results from this field study are consistent with those from several trials carried out with the same breed combinations on our University experimental farm, which is located in the same area. Young bulls crossbred from double-musled Belgian Blue or Piemontese sires and Brown Swiss dams performed

similarly, although those sired by the Belgian Blues were slightly more muscular (Bittante et al. 2018). However, Belgian Blue crossbred heifers outperformed Piemontese crosses, and displayed a different sexual dimorphism, which is related to the different selection objectives of these two double-muscled breeds (Bittante et al. 2018). In fact, double-muscled Belgian Blue breed is selected almost exclusively for beef traits (Coopman et al. 2007) and not for calving ease. Indeed, in purebred breeding, almost the totality of calvings requires the caesarean section (Kolkman et al. 2007). In the case of Piemontese selection index (Albera et al. 2004), less than half of the economic weight is represented by growth rate and muscularity (Pegolo et al. 2020), and the most important trait is calving ease, both direct and maternal (Kizilkaya et al. 2003; Pegolo et al. 2020). The result of this difference in breeding goals is that Piemontese cows are characterised by a much lower incidence of caesarean sections (Albera 2015), and a lower muscularity score than BB cows (Bittante et al. 2018).

It is worth noting that the myostatin mutation causing double-muscling differs in the two sire breeds: the muscle fibres tend mainly towards hypertrophy (same number and length of muscle fibres, but larger thickness respect to conventional beef breeds) in Belgian Blue crosses, whereas they tend towards hyperplasia (same length and thickness, but increase of number of muscle fibres) in Piemontese crosses, with a reduction in intramuscular fat (Verdiglione and Bittante 2013; Bittante et al. 2018). However, the only differences in the beef quality traits were the higher redness and chroma indices of the Piemontese crosses. Studies on the effects of the sire breed used on dairy cows have focussed mainly on conventional beef breeds. The meat of crosses from double-muscled breeds is well-known for its greater leanness (Wheeler et al. 2001), but other often minor differences in meat quality traits compared with conventional beef breeds have also been found (Gariépy et al. 1999; Domingo et al. 2015), including some positive effects on tenderness (Kobolák and Gócza 2002; Zwambag et al. 2013), but also some negative effects on drip loss (Cafferky et al. 2019).

Very few studies have looked at the dam breed in beef \times dairy crossbred young bulls. Tagliapietra et al. (2018) compared crossbred calves from Belgian Blue sires and dairy (Brown Swiss) and dual-purpose (Simmental and Rendena) cows, and found the latter to have some advantage over the former in carcase muscularity, bone percentage, and shear force. In the same project, beef \times dairy crossbred young bulls and heifers showed less of a reduction in quantitative and qualitative performances than purebred double-muscled

young bulls (Schiavon et al. 2011, 2012) when dietary protein was lowered to improve the ecological footprint of beef production (Schiavon et al. 2013, 2019).

Conclusions

The meat from beef \times dairy crossbred calves was found to have valuable qualitative characteristics, whether it was beef produced on the dairy farms of the calves' origin, or veal or beef produced by specialised intensive fatteners. With regard to veal production, the meat quality characteristics did not differ appreciably between BB \times HF, taken as reference, and the other combinations of different dam and sire breeds. With regard to intensive beef production, the meat from beef \times dairy young bulls had greater lipid and dry matter contents, lower cooking losses, and minor differences in pH, cholesterol, and haem iron contents compared with purebred Charolais and beef crossbred calves from suckler cows, but there were no differences in shear force and colour indices. The only differences in quality traits between BB \times HF and the various beef \times dairy breed combinations were the higher lipid content (ether extract), lower cooking losses and lighter (higher L^*) meat of BB \times BS, and the lower haem iron, and higher lightness, yellowness, and hue colour indices of BB \times CB.

In conclusion, inseminating dairy cows with semen from current beef sires, which is now facilitated by the use of sexed semen to produce replacement heifers, can produce crossbred calves of high value to different farming systems, not only for growth, muscularity and carcase characteristics, but also for their meat quality characteristics.

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Ethical approval

Animal Care and Use Committee approval was not obtained for this study because the data were obtained from an existing database; the analysed records were collected after slaughtering of animals in a commercial abattoir. The authors did not have direct control over the care of the animals included in this study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The results and analyses presented in this paper are freely available upon request.

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