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Cull cow carcass traits and risk of culling of Holstein cows and 3-breed rotational crossbred cows from Viking Red, Montbéliarde, and Holstein bulls

M. Piazza, M. Berton,* N. Amalfitano, G. Bittante, and L. Gallo
Department of Agronomy, Food, Natural resources, Animals and Environment (DAFNAE), Viale dell'Università 16, 35020 Legnaro, Padova, Italy

ABSTRACT

Culled dairy cows represent a considerable source of meat production, but their carcasses may vary greatly in quality because of the wide variation in the age, stage of lactation, breed, body condition, and other characteristics of the cows at slaughter. However, the effect of crossbreeding on the value of culled cows has so far received little investigation. The aim of this observational study was to compare a range of carcass attributes of cull cows from 3-breed rotational crossbreeding using Viking Red, Montbéliarde (MO), and Holstein (HO) bulls with those of HO purebred cows. Data on 1,814 dairy cows were collected. Cows were reared together in one herd and slaughtered in 4 slaughterhouses. The carcass weight, fleshiness, and fatness scores, the total value, and the price (€/kg) of each cow carcass were recorded. The culling of a few cows in the sample (n = 86) was classified by the farm manager as "urgent" following a diagnosis of injury or sickness, and this information was recorded. Carcass traits were analyzed with a mixed model which included the fixed effects of parity, days in milk, genetic group (purebred HO, 787 cows, and crossbred cows, classified according to the breed of sire within crossbreds, with 309, 428, and 290 cows sired by Viking Red, MO, and HO bulls, respectively), and interactions, and the random effects of month × year of the date of slaughter, and slaughterhouse. Logistic regression was used to investigate the association of parity, days in milk and purebred or crossbred origin with unplanned, "urgent" culling compared with regular culling. Average carcass weight across genetic groups was 297 ± 65 kg, average price €2.03 ± 0.53/kg, and average value €631 ± 269. Compared with HO, crossbred carcasses were 7 to 12% heavier depending on the breed of sire, were graded + 0.12 to + 0.28 units higher for fleshiness and + 0.26 to + 0.30 units higher for fatness, and fetched an 8 to 11% higher price. As a consequence, compared with purebred HO, carcasses from crossbreds had 15 to 24% higher value (€84 to €133 more per cow), with crossbred cows sired by MO showing the greatest values. Moreover, compared with the HO cows, the crossbred cows had a 37% lower risk of being urgently removed from the herd, which raises welfare concerns and may reduce the salvage value of cull cows. Because cull cows represent a supplemental source of income for dairy farmers, the greater overall value of crossbred cull cows should be taken into account in evaluating the economic effectiveness of crossbreeding schemes.

Key words: dairy beef, slaughter cows, carcass traits, crossbreeding, Holstein Friesian

INTRODUCTION

Culling is important in the management of dairy herds, as less-productive, old, infertile, or unhealthy cows need to be continually replaced with younger and genetically superior heifers to maximize profitability. Although there is considerable variation, the average culling rate in the dairy sector is around 30% (Stojkov et al., 2018), which means that culling provides a consistent number of animals per year for meat production. Reproduction, mastitis, low production, and injury have been reported as predominant reasons for culling (Moreira et al., 2021a), although often the causes for disposal cows are several, distant, and not always fully evident (Fetrow et al., 2006). Dairy cows accounted for nearly 10% of commercial beef production in the United States in 2019 (Moreira et al., 2021b). Likewise, over 30% of bovine meat in the European Union came from cull cows (Eurostat, 2017), mostly of dairy breeds, whereas about 19% of the cattle slaughtered in Italy in 2020 were from dairy herds (ISTAT, 2021). However, despite their notable contribution to the beef industry, the importance of cull dairy cows and the factors affecting their value have received little attention in research.

The economic value of cull cows largely depends on their BW and several other characteristics of the cow, such as age and stage of lactation at culling, muscle conformation, and fattening grade, as well as potential

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*Corresponding author: marco.berton.1@unipd.it

visual defects, which directly affect the market price (Moreira et al., 2021a). As cull cows vary greatly in these characteristics (Vestergaard et al., 2007), wide variation in their value should also be expected.

Breed is another of the factors directly related to the cow that influences the carcass price and value of dairy cull cows. Bazzoli et al. (2014) compared the carcass attributes of cull cows of different dairy and dual-purpose breeds and reported that breed strongly affected carcass weight, price and value, with relevant differences not only between, but also within the dairy and dual-purpose categories. Gallo et al. (2017) also observed significant differences in the characteristics and value of cull cow carcasses of different dairy and dual-purpose breeds.

There has, however, been little research on the carcass traits and value of crossbred dairy cull cows. Crossbreeding programs have gained ground in recent years because of the need to improve the functional traits of high-yielding dairy breeds, mainly Holsteins. Crossbreeding has been found to have positive effects on milk quality, and on the fertility and udder health of cows, without detrimental effects on the daily yield of milk nutrients (Malchiodi et al., 2014; Shonka-Martin et al., 2019; Saha et al., 2020), and is therefore considered beneficial for the sustainability of dairy cattle farms (Buckley et al., 2014). Of the various crossbreeding programs, interest is growing in the 3-breed rotational system using Holstein (**HO**), Montbéliarde (**MO**), and Viking Red (**VR**) breeds, which is marketed internationally as ProCROSS by Coopex Montbéliarde (Roulans, France) and Viking Genetics (Randers, Denmark). Several studies have investigated the effects of this crossbreeding program on various production, functional, and body traits (Malchiodi et al., 2014; Shonka-Martin et al., 2019; Saha et al., 2020), and shown it to be a profitable alternative to the HO pure-breeding system (Hazel et al., 2021). However, the value of culled cows originated from this crossbreeding scheme has been only scarcely investigated (Hazel et al., 2021).

Therefore, this observational study aimed to compare some carcass attributes and the overall carcass value of dairy cull cows originated from a 3-breed rotational scheme using VR, MO, and HO bulls with those obtained by HO purebred (**PU_HO**) cows.

MATERIALS AND METHODS

Animals Enrolled in the Study

The study involved 1,814 dairy cull cows slaughtered from 2015 to 2020 in 4 different commercial slaughterhouses, labeled A, B, C, D; around 73% of the cows in the study went to A, and around 17, 6, and 4% went to B, C, and D, respectively. Ethical approval was not sought for the present study because research did not involve direct manipulation of animals by authors. Moreover, the study was carried out following the recommendations of the ARRIVE guidelines (Kilkenny et al., 2010). The cows came from one dairy farm located in the Emilia-Romagna region of Italy (province of Modena), in the Parmigiano Reggiano protected designation of origin hard cheese production area. The farm had been using for more than a decade the 3-breed rotational crossbreeding system known as ProCROSS, according to a mating design descripted in details by Saha et al. (2020) and Hazel et al. (2021). Purebred and crossbred cows were reared together and managed as one group. The animals were kept in freestalls with cubicle and were milked twice per day. Cows were fed the same TMR, based on dry roughage, mainly alfalfa and meadow hay, and concentrates, and with no silage, in accordance with the regulations governing the production of Parmigiano Reggiano hard cheese.

Two to 4 shipments of culled cows, each consisting on average of 9 ± 5 cows (mean ± SD), were delivered each month to the slaughterhouses, situated between 32 and 37 km from the farm. An average of 26 ± 10 cows were culled monthly, and both PU_HO and crossbreds were always present in each monthly delivery. In addition to the scheduled culling of cows, there was also some unscheduled culling of cows (n = 86) due to injury or sickness, classified by the farm manager as “urgent” and requiring prompt removal upon diagnosis. These were frequently delivered individually to the slaughterhouse. As cows sent for salvage slaughter still have a financial value, they were retained for the analyses, whereas euthanized or dead cows and those without carcass value were not enrolled in the study (n = 15).

Overall, the study involved 787 PU_HO, and 1,027 crossbred cull cows. Crossbreds were classified acccording to the breed of sire as follows: those sired by VR (**VR_CR,** 309 cows), including the following breeds combinations: VR(HO), VR(MOHO), VR(HOMOVRHO), VR(MOHOVRMOHO); those sired by MO (**MO_CR**, 428 cows), including the following breeds combinations: MO(HO), MO(VRHO), MO(HOVRMOHO), MO(VRHOMOVRHO); and those sired by HO (**HO_CR**, 290 cows), including the following breeds combinations: HO(VRMOHO), HO(MOVRHO).

Data Collection and Variable Definitions

The data collected on farm comprised the following information for each cow: the genetic group (PU_HO or breed combinations of crossbreds), the parity order, the date of the last calving, the date of culling, and the culling type (scheduled or urgent, as defined above). The reasons for culling were not recorded regularly on the farm, and were therefore unavailable for this study. Similarly, BW of dairy cows was not available because cows were not regularly weighed on the farm.

The following information was collected at the slaughterhouse for each cow (experimental unit): carcass weight (**CW**, kg), carcass value (**VAL**, €), and fleshiness (**FL**) and fatness (**FT**) scores. The grading system based on the classes developed by the European Parliament and Council Regulation (EU) No. 1308/2013 has been used for the assessment of beef quality of carcasses, with FL evaluated according to the SEUROP grading system from S (superior) to P (poor) fleshiness, and FT evaluated from 1 (low) to 5 (very high) fat cover (DG AGRI, 2011). Fleshiness and FT were recorded only from 2016 onward, and for 1,421 cows.

Data Editing and Statistical Analysis

Before analysis, the difference in days between the date of culling and the date of the last calving (**DIM**) have been calculated, whereas the carcass price (**PRI**, €/kg) has been computed as the ratio of VAL to CW (€/kg). Parity was classified into 5 classes (first parity, n = 304 cows; second parity, n = 514 cows; third parity, n = 432 cows; fourth parity, n = 310 cows; ≥ fifth parity, n = 254 cows), DIM was classified into 5 classes of 100 d each (≤100, n = 284 cows; 101 to 200, n = 291 cows; 201 to 300, n = 420 cows; 301 to 400, n = 478 cows; >400, n = 341 cows), and the cows' genetic group was classified into 4 classes (PU_HO, VR_CR, MO_CR, HO_CR). The FL scores were converted into numeric variables ranging from 1 (P) to 6 (S).

After a preliminary analysis performed to check assumptions required for model fitting and hypothesis testing, carcass traits (CW, PRI, VAL, FL, and FT) were analyzed using PROC MIXED version 9.4 (SAS Institute Inc., version 9.4) and the following linear mixed model:

$$\mathrm{y}_{ijklmn} = \mu + PAR_i + DIM_j + (PAR \times DIM)_{ij} + M\_Y_k + SLH_l + GG_m + (GG \times PAR)_{im} + (GG \times DIM)_{jm} + e_{ijklmn},$$

where y_{ijklmn} is the trait of interest; μ is the overall mean; PAR_i is the fixed effect of the ith parity ($i = 5$ classes); DIM_j is the fixed effect of the jth class of days from calving ($j = 5$ classes); $(PAR \times DIM)_{ij}$ is the interaction effect between parity and days from calving; GG_m is the fixed effect of the mth class of the genetic group of cows ($m = 4$ classes); $(GG \times PAR)_{im}$ is the interaction effect between the parity and the genetic group of cows; $(GG \times DIM)_{jm}$ is the interaction effect between the parity and the genetic group of cows; M_Y_k is the random effect of the month-year group of culling ($k = 67$); SLH_l is the random effect of slaughterhouse ($l = 4$); and e_{ijklmn} is the random residual. Month-year group of culling, SLH, and the residuals were assumed to be normally distributed with a mean of zero and variances of σ_k^2, σ_l^2, and σ_e^2, respectively.

Least squares means between genetic groups were contrasted using a Bonferroni correction for multiple testing. Moreover, an orthogonal contrast [PU_HO vs. (VR_CR + MO_CR + HO_CR)] was estimated to investigate the differences between purebreds and crossbreds taken as a mixture of generations and sire breeds representing the 3-breed rotational system.

Logistic regression was used to investigate the association of a set of explanatory variables with unscheduled "urgent" culls (compared with scheduled culls) through estimates and confidence intervals of the odds ratios (**OR**), a multiplicative measure of probability that ranges from 0 to infinity. Odds ratio was used to evaluate differences in the risk of being urgently culled among the effects considered. Odds ratio values of >1 or <1 indicate a greater or lower probability of a cow being urgently culled, compared with a reference condition expressed by the intercept of the logistic regression model. The 95% confidence interval represents the range within which the true OR of the population is expected to fall; if the 95% confidence interval included the value 1.00, the group of concern is assumed to be not significantly different from the reference. The LOGISTIC procedure of SAS was run with a model in which first parity PU_HO cows culled in the first 100 DIM were considered the "reference" animals, and the fixed effects of parity, DIM, and PU_HO or crossbred origin were included as categorical explanatory variables. In all the models tested, a given effect (or interaction) was declared significant at $P < 0.05$.

RESULTS

Descriptive Statistics of Carcass Traits

Descriptive statistics of carcass characteristics are reported in Table 1. In this study, cows that were culled had on average 2.9 ± 1.4 lactations and were 274 ± 150 DIM (data not shown in the table). The average CW was 297 kg and most cows had the lowest muscularity class (P = score 1.0), so the average FL score was 1.3 points. The average FT score was higher

Table 1. Descriptive statistics of weight, fleshiness and fatness score, price, and value of carcasses

Trait	Weight, kg	Fleshiness[1]	Fatness[2]	Price, €/kg	Value, €/cow
Cows, n	1,814	1,421	1,421	1,814	1,814
Mean	297	1.32	2.19	2.03	631
SD	65	0.5	0.92	0.53	269
Minimum	92	1	1	0.3	46
Maximum	482	3	4	3.5	1,401

[1]On a 6-point scale (higher numbers indicate greater fleshiness).

[2]On a 5-point scale (higher numbers indicate fatter carcass).

(2.2 points), as was its variability (SD = ± 0.9 scores). The average total value of a cull cow carcass was close to €630, and the variation in VAL was nearly twice the variation in CW. Derived from VAL and CW, the average carcass PRI was €2.03/kg, with a coefficient of variation close to 26% and rather constant across years.

Sources of Variation in Carcass Traits

The results for the carcass traits are given in Table 2. Both parity and, to a greater extent, DIM significantly influenced all carcass traits considered, with the exception of FT, which was similar in cows of different parities. Moreover, a significant interaction between parity and DIM was observed for all carcass traits. In multiparous cows (Figure 1), CW increased almost linearly with increasing DIM class, with comparable trend in cows of different parity. Carcass weight also increased with increasing parity within DIM class in multiparous cows. Conversely, primiparous cows showed a different pattern of variation, because CW increased at increasing DIM until 200 DIM and from 400 DIM thereafter, whereas the increase in CW between 200 and 400 DIM was negligible in cows culled during their first parity. Primiparous and multiparous cows showed also a different trend of variation of FL and FT at increasing DIM at culling (Figure 2). Indeed, both carcass attributes linearly increased with the advancing of DIM in multiparous cows, and FL tended also to increase at increasing parity. Conversely, in primiparous cows both FL and FT nominally decreased at increasing DIM at culling until around 300 DIM, and increased thereafter, although no significnt difference was detected comparing least squares means of FL and FT of primiparous cows culled at different DIM. As a consequence, PRI and VAL (Figure 3) increased with increasing DIM class in multiparous cows, whereas their increase in primiparous cows was substantial only for cows culled from 300 DIM thereafter. Carcass price and VAL also increased with increasing parity order within DIM class, but the greatest differences concerned primiparous cows culled between 200 and 400 DIM compared with multiparous ones.

Genetic group significantly ($P < 0.01$) affected all carcass traits considered (Table 1). Compared with PU_HO carcasses, carcasses from crossbreds were 7 to 12% heavier, depending on the breed of sire, were graded 0.12 to 0.28 units higher for FL and 0.26 to 0.30 units higher for FT, and fetched a 8 to 11% higher PRI (Table 3). As a consequence, compared with PU_HO, carcasses from crossbreds had 15 to 24% higher VAL (+€84 to +€133/cow), with MO _CR cows showing the greatest values.

Table 2. Results from the mixed model for weight, fleshiness, and fatness score, price, and value of carcasses: F-values and significance of parity and DIM classes and of genetic group of the cows; percentage of variance explained by the random effects of month-year (M_Y) and slaughterhouse (SLH)

Item	Weight, kg	Fleshiness	Fatness	Price, €/kg	Value, €/cow
Parity (PAR)	20.11**	2.74*	1.95	3.72**	9.66**
DIM	135.83**	23.30**	36.76**	76.09**	104.52**
PAR × DIM	1.66*	2.39*	2.45**	3.16**	2.67**
Genetic group (GG)	33.87**	60.99**	8.66**	26.68**	31.33**
GG × PAR	0.75	1.64	1.10	0.97	0.66
GG × DIM	1.37	2.80**	1.19	1.61	1.57
M_Y, %	1.05	2.18	0.50	12.39	4.37
SLH, %	0	0	0.89	3.77	0
RMSE	51.91	0.46	0.84	0.44	220

[1]RMSE = root mean square error.

$*P < 0.05$; $**P < 0.01$.

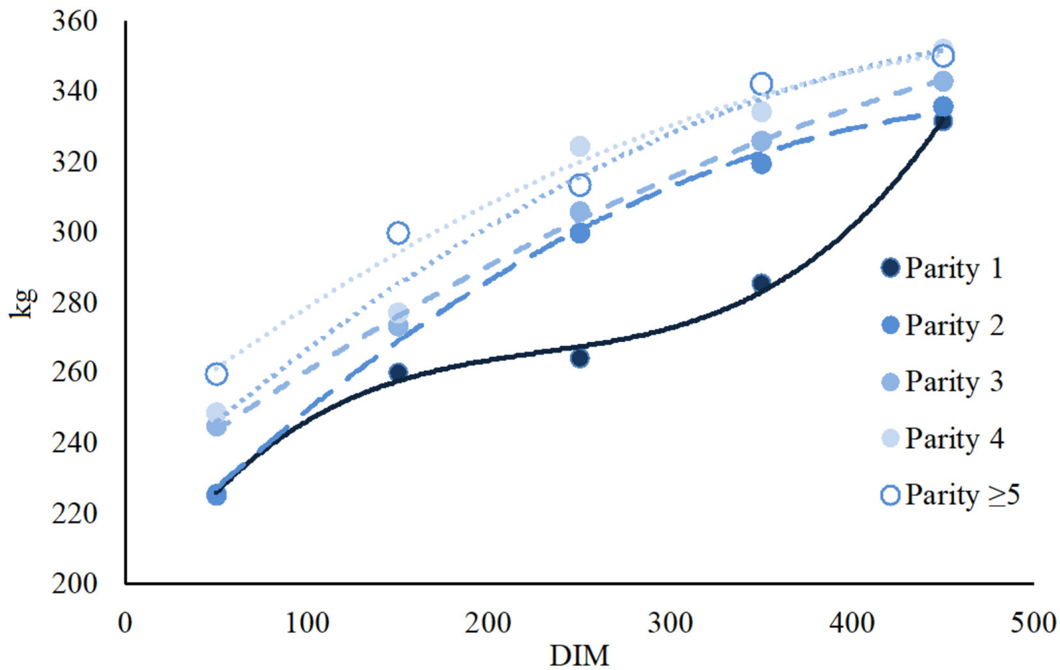

Figure 1. Least squares means of interaction between parity and lactation stage (DIM) of the weight of carcasses obtained from purebred Holstein and 3-breed rotational crossbred cull cows.

Relative Risk of "Urgent" Culling

The estimated OR of parity and DIM class, and of crossbreds for unscheduled urgent culling are presented in Table 4. Eighty-six cows were culled outside the scheduled replacement plan (i.e., 4.7% of the sample).

Parity order did not appear associated with the the risk of being urgently culled ($P > 0.05$). However, cows with DIM of 200 or more had a significantly lower risk of being urgently culled than those with DIM of ≤100, and OR progressively decreased with the increasing length of time since calving. The origin of the cows (PU_HO or crossbreds) also significantly affected unscheduled urgent culls ($P < 0.04$), and crossbred cows were at lower risk of being urgently removed from the herd than PU_HO cows (OR = 0.63).

DISCUSSION

Variation in Carcass Traits and Effects of Parity and Lactation Stage at Culling

Parity order at culling in this study averaged 2.9, and 69% of cull cows were in their first 3 lactations, which is consistent with data reported by Moreira et al. (2021a) for US dairy operations. Similarly, the average DIM at culling of around 274 d is comparable with the average calving to culling interval found in a large sample of dairy and dual-purpose cull cows reared in northern Italy (Gallo et al., 2017).

Carcass traits and the market value of cull cows are expected to be characterized by large variations, because cows no longer suitable for milk production may be removed at any parity and at any calving to cull interval, resulting in substantial differences in age, stage of lactation, and body condition at slaughter (Shemeis et al., 1994; Vestergaard et al., 2007). The average CW in this study was almost 300 kg, greater than the average CW of dairy and dual-purpose cull cows reported by Gallo et al. (2017), Minchin et al. (2009), and Berry et al. (2021; 257, 277, and 289 kg, respectively), comparable to the average CW of dairy cull cows reported by Harris et al. (2018) in the National Beef Quality Audit 2016 (303 kg), and lower than the average CW reported by Moreira et al. (2021b; 325 kg). The coefficient of variation of CW in this study was close to 22%, consistent with the variation in CW reported by Moreira et al. (2021b) and Harris et al. (2018), which ranged from 21 to 28%. Lastly, the average FL and FT scores found in this study were slightly higher than those reported by Minchin et al. (2009), Gallo et al. (2017), and Berry et al. (2021) for dairy cull cows.

Both parity and, with a greater extent, DIM significantly affected CW and carcass attributes, but the pattern of variation of carcass traits at increasing DIM was partly different in primiparous and multiparous cows.

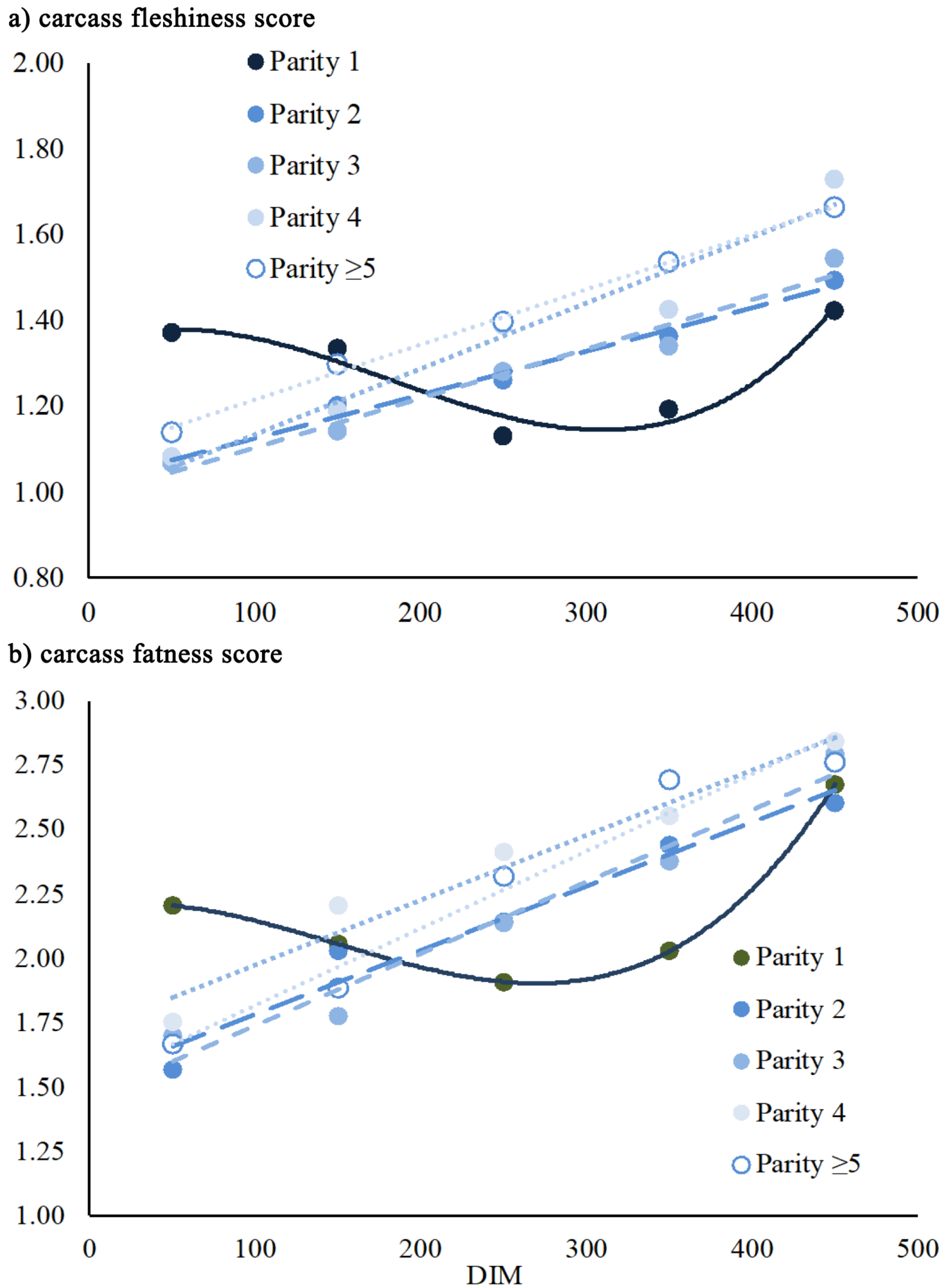

Figure 2. Least squares means of interaction between parity and lactation stage (DIM) of (a) fleshiness score (1 to 6) and (b) fatness score (1 to 5) of carcasses obtained from purebred Holstein and 3-breed rotational crossbred cull cows.

Carcass weight increased with increasing parity for all class of DIM at culling, whereas the increase in FL, FT, and PRI with age at culling was slight but consistent in multiparous cows and followed an inconsistent pattern of variation within class of DIM at culling in primiparous cows. Similar associations between the lactation order or the age of cows at culling and CW have been reported by Seegers et al. (1998) and Gallo et al. (2017). The relationships between age at culling and carcass quality seem less consistent: Moreira et al. (2021b) found that dairy cows removed from the herd in later lactations fetched a lower PRI than those culled

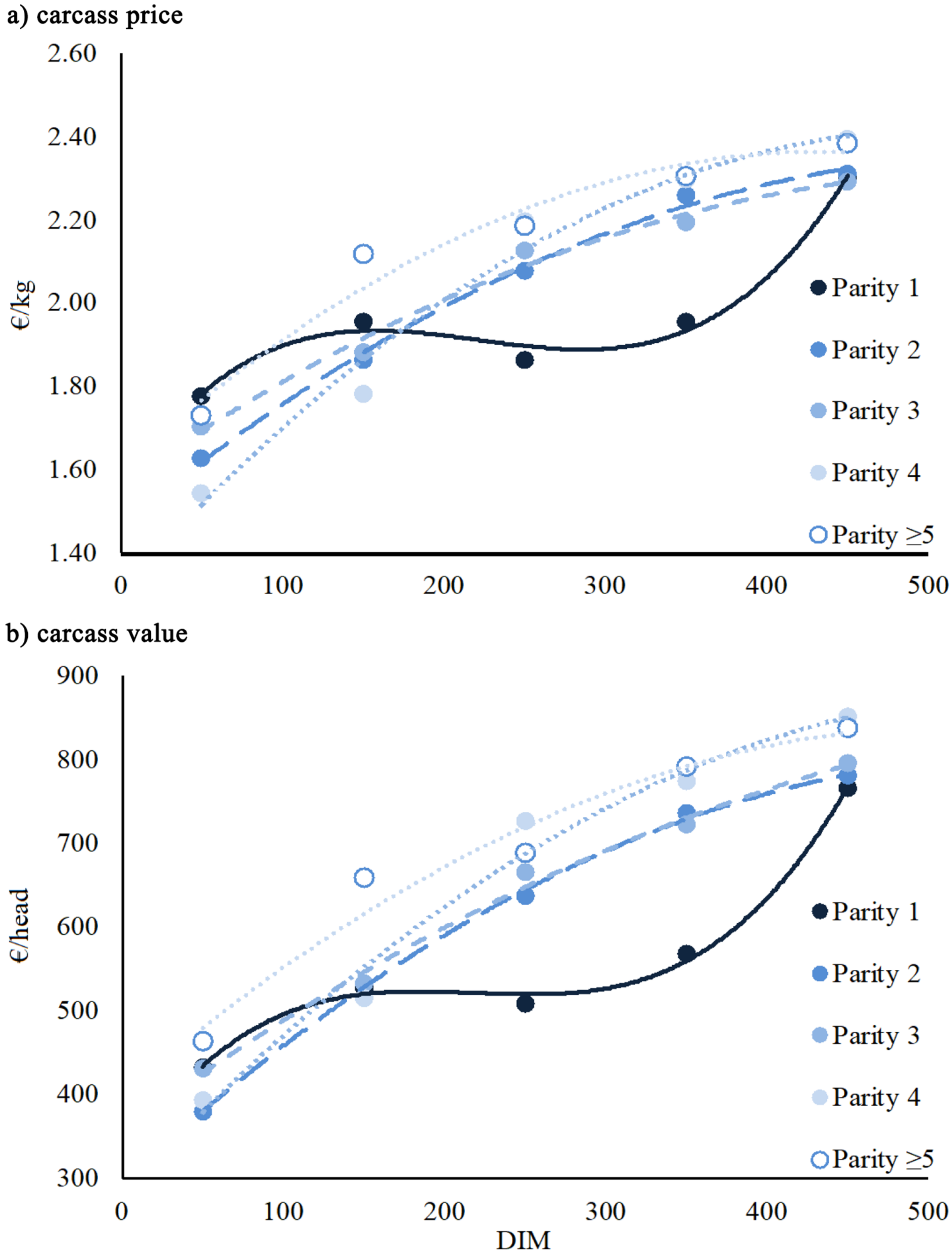

Figure 3. Least squares means of interaction between parity and lactation stage (DIM) of (a) price and (b) total value of carcasses obtained from purebred Holstein and 3-breed rotational crossbred cull cows.

in the first 2 lactations; Gallo et al. (2017) found only slight associations between the FL and FT of carcasses of dairy and dual-purpose cull cows and the age of the cows at culling, whereas the PRI was unaffected. Shemeis et al. (1994) also reported that age had no significant effect on scores related to carcass conformation and FT. However, none of these studies considered an interaction between the lactation number and the DIM at culling in their analyses.

In general, CW increased with the increasing interval between calving and culling, although this trend was more consistent in multiparous than in primiparous

Table 3. Least squares means and SEM for weight, fleshiness, and fatness score, price, and value of carcasses from the 3-breed rotational crossbred cows classified according to the sire breed (Viking Red, VR, n = 309 cows; Montbéliarde, MO, n = 428 cows; and Holstein, HO, n = 290 cows) or combined (CR, n = 1,027 cows) compared with those from purebred HO cull cows (n = 787 cows)

Item	Weight, kg	Fleshiness	Fatness	Price, €/kg	Value, €/cow
Purebred HO					
Mean	278.4	1.17	2.02	1.89	550
SEM	2.19	0.02	0.06	0.06	10.5
Crossbreds sired by VR					
Mean	298.2*	1.36*	2.32*	2.11*	645*
SEM	3.79	0.06	0.08	0.06	15.4
Crossbreds sired by MO					
Mean	311.4*	1.46*	2.27*	2.13*	683*
SEM	2.81	0.03	0.07	0.06	12.9
Crossbreds sired by HO					
Mean	298.2*	1.30*	2.28*	2.05*	634*
SEM	3.79	0.04	0.08	0.06	16.8
Combined CR					
Mean	303.9*	1.38*	2.28*	2.10*	659*
SEM	1.90	0.02	0.06	0.05	9.7

*Significant difference ($P < 0.01$) from purebred HO.

cows. Also FL and FT consistently increased at increasing DIM in multiparous cows, whereas they were nominally lower, although not significantly different, in primiparous cows culled between 200 and 400 DIM compared with those culled in early or very late lactation. It is well known that body reserves are mobilized in early lactation to support milk production, mainly as body fat and, to a certain extent, as body protein, leading to a reduction in weight and condition scores (Gallo et al., 1996; Phillips et al., 2003) which then recover from the second to third month of lactation onward. Moreover, culling due to injury and poor health status is more frequent during early lactation, and this may contribute to reduce the value of cows culled early after calving (Pinedo et al., 2010; Moreira et al., 2021a). The increase in carcass quality traits with increasing DIM after the lactation peak was therefore expected, and the findings that cows culled later in lactation fetch higher PRI and have a greater VAL due to better weight and carcass composition are consistent with previous studies (Seegers et al., 1998; Gallo et al., 2017). The different trend of variation of carcass traits at increasing DIM at culling observed for primiparous cows in comparison to multiparous ones may be due to differences in lactation curves (Macciotta et al., 2011) and in pattern of the body reserve mobilization (Gallo et al., 1996), which reflect also the different nutritional competition between milk production and body growth. Moreover, as the cull of a cow at its first lactation may have a particular negative economic impact (Rilanto et al., 2020), it is possible that farmers adopt different criteria for cows of first parity compared with multiparous when taking culling decisions.

Table 4. Estimated odds ratio (OR) and 95% confidence interval of parity and DIM class, and genetic group for unscheduled urgent culling (n = 1,814 cows)

Item	OR[1] Point estimate	OR[1] 95% CI		*P*-value
Parity class				
First (reference)	1	—	—	—
Second	0.733	0.380	1.414	>0.05
Third	0.674	0.340	1.334	>0.05
Fourth	0.976	0.480	1.949	>0.05
≥Fifth	0.469	0.189	1.160	>0.05
DIM class				
≤100 (reference)	1	—	—	—
101–200	0.675	0.404	1.991	>0.05
201–300	0.304	0.160	0.575	<0.001
301–400	0.193	0.095	0.391	<0.001
>400	0.113	0.043	0.294	<0.001
Genetic group				
Holstein (reference)	1	—	—	—
Crossbred	0.633	0.404	0.991	0.04

[1]OR >1 (OR <1) means a higher (lower) risk of being urgently culled unscheduled than the reference class.

Effects of VR, MO, and HO Rotational Crossbreeding on Carcass Traits

In the present study, the carcasses of crossbred cows were found to be superior to those of PU_HO cows for all the attributes considered, resulting in a 20% greater total VAL. Montbéliarde sired cows showed the greatest VAL and PRI and the highest FL within crossbreds, but all the breed combinations considered were substantially superior to PU_HO for the traits investigated.

Breed is known to be one of the main sources of variation of carcasses from cull cows. Bazzoli et al. (2014)

compared cull cows of different dairy and dual-purpose breeds, and they found that HO cows yielded lighter carcasses, fetched a lower PRI and had a lower VAL than Brown Swiss, Simmental, and other dual-purpose cull cows. Likewise, Gallo et al. (2017) reported that the CW, FT, conformation, and PRI of carcasses of cull cows varied significantly according to breed, with Simmental always superior to HO. Zanon et al. (2020) also observed a clear effect of breed on the auction price of cull cows, with HO fetching the lowest price compared with other dairy cattle breeds reared in the Alpine region.

Higher revenue from cull cows from this 3-breed crossbreeding system compared with their PU_HO herd-mates was also reported by Hazel et al. (2021) in a study investigating the lifetime profit of PU_HO and crossbred cows kept in high-performance commercial herds in Minnesota. In that study, compared with PU_HO, the cull cow revenue was nearly 16% higher for the combined 3-breed crossbreds, with a slight greater value for MO_CR than for VR_CR cows.

The higher overall value of carcasses of crossbred cull cows compared with carcasses of PU_HO was due almost equally to their greater CW (+9%) and PRI (+11%). The higher PRI may be attributed to the greater FL and FT of carcasses from crossbred compared with those from PU_HO. Literature investigating the carcass attributes of purebred and crossbred dairy cull cows is scarce, and mainly referred to breed combinations different from those of the present study (Berry et al., 2018; Coyne et al., 2019). However, some useful indications can be gathered from studies dealing with the body traits of cows belonging to these genetic groups. Crossbred cows have generally been found to have higher BCS compared with their PU_HO herdmates. Several authors have reported this to be the case with this 3-breed rotational crossbreeding scheme (Saha et al., 2018; Shonka-Martin et al., 2019; Hazel et al., 2020), whereas greater backfat thickness have also been found in crossbred cows originated from crossbreeding programs involving Brown Swiss (Blöttner et al., 2011). The VAL of cull dairy cows depends on their body composition in terms of the proportions of muscle and fat (Moreira et al., 2021a), and BCS significantly affects the carcass conformation, PRI and VAL of cull dairy cows (Shemeis et al., 1994; Ahola et al., 2011).

Among breeds used as sire in the crossbreeding scheme, MO_CR provided the best performance in term of FL, with VR_CR just nominally better than HO_CR. Similar conformation score between HO and Danish Red young bulls, a subpopulation included in the VR (Shonka-Martin et al., 2019), has been reported by Albertí et al. (2008) in a study comparing carcass characteristics of young bulls of 15 European breeds. However, the MO, as dual-purpose breed, has been actively selected also for improving muscularity scores, and it is known to provide carcasses heavier and characterized by greater FL, PRI, and VAL than HO (Cabaraux et al., 2005; Balandraud et al., 2018). Indeed, an increase in the proportion of MO compared with HO breed has been associated with an increase in the selling price of crossbred cows at livestock marts in Ireland (McHugh et al., 2010), and greater condition score, CW, PRI, and VAL have been reported for MO cull cows compared with HO (Evans et al., 2004).

Unscheduled Urgent Culling

Voluntary culling occurs when a cow is considered no longer of value to the herd, and the producer decides to remove it and replace it with a younger animal with greater productivity potential, whereas involuntary culling occurs when the producer needs to remove a cow due to infertility, illness, or injury (Moreira et al. 2021a). Nonetheless, both voluntary and involuntary removal are generally planned decisions and result in scheduled, nonurgent cull events. However, in some extreme circumstances, ill health, or injuries not only impair the cow's productivity, but also cause notable suffering (Cockram, 2021), necessitating its removal outside the ordinary schedule, often urgently. Emergency culling typically follows a diagnosis of milk fever, downer cow syndrome, left displaced abomasum, severe teat problems, or foot and leg problems (Orpin and Esslemont, 2010).

In this study, urgent culling represented just under 5% of all removals from the herd, and it occurred irrespective of the parity order of the cows. It is known that the overall culling risk is increasing with lactation number (Hadley et al., 2006), and this is caused by both voluntary and involuntary culling. What is not well known is the effect of parity on that part of involuntary culling that lead to urgent culling. The risk of urgent removal decreased with increasing stage of lactation and was much lower from 200 DIM onward than in the previous phases. Cows in their first 100 DIM had only a nominally greater risk of urgent removal compared with those in mid lactation (100–200 DIM). In general, the highest risk of culling occurs shortly after calving, it then drops but increases again in the later stages of lactation (Fetrow et al., 2006). Nevertheless, culling due to injury and sickness, which is likely to be urgent and unscheduled, occurs more frequently in early lactation (Pinedo et al., 2010; Langford and Stott, 2012).

Crossbred cows were at a significantly lower risk of urgent unscheduled culling than purebred HO. Although the reason for urgent culling was only sporadically recorded, and hence was not included in this study, it is fair to assume it was mainly injury and sickness (where it was recorded, the cause was mainly given as “legs”). Aside from welfare concerns, culling due to extremely poor health status may drastically reduce the salvage value of cull cows (Stojkov et al., 2018; Moreira et al., 2021a). Indeed, in this study the average value fetched by urgently culled cows was around €160 ± 95, compared with the €654 ± 253 paid for regularly culled cows. Crossbreeding in dairy cattle has been associated with improved immunity (Cartwright et al., 2012), lower total health costs, fewer health disorders (Blöttner et al., 2011; Hazel et al., 2020), and greater robustness (Sørensen et al., 2008). This greater general robustness may also help explain the finding in this study that crossbred cows are at a lower risk of urgent unscheduled culling than PU_HO cows.

CONCLUSIONS

The data collected on Hostein cows and cows originated from a 3-breed rotational crossbreeding scheme reveal that the carcasses of the crossbred cull cows were heavier, better graded for FL and FT, fetched higher prices, and had a total value nearly €100 greater than the carcasses of their PU_HO herd-mates. Furthermore, crossbred cows had a lower risk than PU_HO of urgent unscheduled culling, which raises welfare concerns and results in a drastic reduction in the salvage value of cull cows. Because cull cows represent a supplementary source of income for dairy farms, the superiority of crossbred cows in terms of the total value of cull cows should be taken into account when evaluating the effectiveness of crossbreeding schemes.

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ORCIDS

M. Piazza https://orcid.org/0000-0002-1764-8853
M. Berton https://orcid.org/0000-0002-2351-3090
N. Amalfitano https://orcid.org/0000-0001-6030-1620
G. Bittante https://orcid.org/0000-0001-7137-7049
L. Gallo https://orcid.org/0000-0002-8908-5105