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RESEARCH

Growth rate, carcass characteristics and meat quality of German Holstein and Jersey bull calves grazed on two different swards

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Abstract Pasture-based veal production of dairy bull calves might be a sustainable alternative to conventional veal production, as access to pasture allows the expression of natural behaviors, and thus contributes to calf welfare. However, scientific data on growth rate, carcass characteristics and meat quality have not yet been reported. The main purpose of the study was to test whether a clover-grass sward with or without herbs results in acceptable performance, carcass characteristics and meat quality in German Holstein and Jersey bull calves. We kept 111 animals (Holstein: 80, Jersey: 31) over three years under whole-day strip grazing conditions and fed small amounts of concentrates daily. Slaughter took place at 32 ± 2 weeks of age after grazing for 75 ± 22 d. Using Bayesian linear mixed models, sward composition did not influence growth rate, carcass characteristics, or meat quality. However, weight at slaughter, longissimus muscle area and the intramuscular polyunsaturated fatty acid percentage increased ($P < 0.05$) with increasing time the calves spent grazing on the experimental paddock. Conversely, the monounsaturated fatty acids percentage in carcass meat decreased ($P < 0.05$) as grazing time increased, suggesting a positive effect of grazing on the fatty acid profile. Pasture grazing can thus be a promising approach for dairy bull calves, producing a favorable fatty acid profile in veal.

Keywords Veal · Grazing · Herbs · Organic dairy farming · Pasture · Forage feeding system

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Introduction

In dairy farming, calves that are not to be used as replacements for the dairy herd typically leave the farm within a few weeks of birth to be finished as beef. This is especially true for the bull calves, since only female calves are reared as replacement dairy cows. Due to the absence of well-developed veal or dairy beef markets, surplus dairy calves might be culled or transported to fattening farms with inadequate husbandry conditions within the first few weeks of life (reviewed by Bolton and Keyserlingk 2021). Transportation of young calves raises welfare concerns, as the animals face risks like hunger, dehydration, disease, injury, stress from handling, social mixing, and unfamiliar environments, as reviewed by Roadknight et al. (2021). This is also a challenge in organic farming, where the majority of male calves is sold to conventionally managed fattening units (Spengler-Neff et al. 2023). To address the farmers' needs and the public's wishes, profitable and animal friendly opportunities are required to raise dairy calves. One possibility may be growing the calves for veal production on pasture. According to the regulations of the European Parliament and Council (No. 1308/2013, ANNEX VII), the sales description for meat of bovine animals aged less than eight months (about 242–245 d) is veal.

The profitability of grazing for beef was demonstrated by Holmström et al. (2021) using steers of pure dairy breeds slaughtered at 15–28 months. They successfully produced pasture-raised meat that commanded price premiums, while reducing costs for silage and labor demands on pasture compared to indoor bull fattening. Several consumer groups are willing to pay additional price premiums for the pasture-raised attribute, even beyond the premium for organic products (reviewed by Stampa et al. 2020). Moreover, regular beef consumers favor pasture-raised beef and are willing to pay higher prices than for beef from cattle with no access to pasture (Lemos Teixeira et al. 2018). One reason for this preference is the negative environmental impact associated with intensive beef production systems (Lemos Teixeira et al. 2018). In this context, Laca et al. (2021) stated that growing dairy cattle instead of beef breeds on pasture can help to reduce negative environmental impacts and promote the unification of the typically separate industries of milk and beef production. Growing the animals on pasture has the potential to increase biodiversity and enhance soil carbon sequestration with minimal pollution (McNally et al. 2017; Teague and Barnes 2017). Another positive reason for preferring beef from pasture-raised animals is the concern over animal welfare (Lemos Teixeira et al. 2018). Daily grazing has demonstrated significant potential to improve welfare by increased resting comfort, reduced incidence of injuries and diseases, and greater expression of social behaviors, as evidenced in dairy cows (Wagner et al. 2017). Furthermore, grazing allows cattle to express their normal feed intake behavior (Charlton and Rutter 2017). The awareness of these positive aspects of pasture-based animal husbandry motivates consumers for the purchase of pasture-raised products, as reviewed by Stampa et al. (2020).

For calves, known for individual variation in feed intake when offered a choice of diet (Webb et al. 2014), the enrichment of pasture swards with herbs could be beneficial due to the provision of a variety of plants with different nutritional profiles. Two herbs that have become progressively utilized in pastures for cattle due to their enhanced yield and nutritional value (compared to ryegrass) are chicory (*Cichorium intybus* L.) and plantain (*Plantago lanceolata* L.) (Minneé et al. 2017). Besides their enhanced drought tolerance, chicory (reviewed by Pol et al. 2021) and plantain (Skinner 2008) can tap into deeper water and nutrient reserves, providing a nutritional advantage over common grasses and legumes. Furthermore, swards containing plantain can provide grazing animals with better nutrition because of their higher digestibility and metabolizable energy content (reviewed by Pol et al. 2021). Additionally, secondary metabolites of plantain, aucubin and acteoside, have been associated with reduced rumen ammonia production, attributed to their bactericidal properties and potential energy source for rumen microbes, respectively (Navarrete et al. 2016). Grazing on perennial ryegrass/clover swards that include plantain or chicory has been shown to sustain or enhance milk production when ryegrass growth is restricted or its quality declines (Minneé et al. 2017).

Grazing on herb-rich pastures can also improve the nutritional quality of meat, particularly by altering the fatty acid profiles. Linoleic acid (C18:2$n-6$) and α-linolenic acid (C18:3$n-3$) are the only fatty acids ruminants cannot synthesize (both essential to the human body). Ruminants must obtain these through their diet and can convert them to longer chain omega-3 and omega-6 fatty acids (reviewed by Ponnampalam et al. 2024). Forages like grass and clover are rich in C18:3*n-3*, more so than grain-based concentrates, as reviewed by Domaradzki et al. (2017). Moreover, certain pasture herbs, including chicory, can have particularly high *n-3* content depending on the timing of their harvest (Clapham et al. 2005). Therefore, pasture feeding can significantly increase the concentration of essential *n-3* in the intramuscular fat (IMF), as shown in German Holstein bulls, with a 2.8-fold increase of intramuscular *n-3* in the *Musculus longissimus dorsi* compared to concentrate feeding (Dannenberger et al. 2006). These findings were matched by Nuernberg et al. (2005), who also observed a significant increase in *n-3* proportions in the longissimus muscle of Holstein bulls under pasture fattening compared to a concentrate feeding system. Similar effects were found in milk composition of Holstein dairy cows (Atkins et al. 2020), where milkfat content of C18:3*n*−3 increased after 4-week periods of grazing when compared to cows housed indoors and offered total mixed ration (TMR) *ad libitum*. Matching these findings, Jersey cows grazing grass/clover pasture, compared with those fed grass/clover/maize silage, produced milk with 70% higher levels of beneficial *n-3*, which increased by an additional 15% when the cows grazed more diverse pasture (Loza et al. 2023).

Most information on performance in grazing cattle refers to adult or maturing beef or dairy cattle. Less is known about the potential of growing of dairy bull calves on pasture. Therefore, we conducted a study in veal production to investigate the impact of two distinct sward compositions on dairy bull calves until slaughter between six and eight months. The aim of the study was to evaluate the effect of an enriched sward on the growth rate, slaughter characteristics and meat quality of grazed dairy bull calves. Our hypothesis stated that growing dairy bull calves on pasture is feasible and a sward providing a larger herb component would have a positive effect on the growth rate, slaughter characteristics, and meat quality due to a more diverse diet relative to a sward of only grass and clover.

Included in this main experiment was a sub-study that demonstrated the positive effect of grazing on the abomasal health of the bull calves. Some details of the present study have been already reported (Simon et al. 2023).

Animals, material, and methods

The research took place from 2018 to 2020 at the Thünen Institute research farm in northern Germany (53° 46′ 8.335" N, 10° 31′ 10.531" E, animal experiment number V244-29,138/2019, MELUND Schleswig–Holstein, following the German Animal Welfare Act, Federal Republic of Germany, 2018). Farm management adhered to the EU Regulation No. 889 for organic production (EC 2008).

Experimental paddock

The experimental paddock consisted of 3 ha grassland, which had been ploughed in 2016 and parted into two equal sized plots, each sown with a different sward (Table 1).

In the Grass (GRS) treatment, the primary constituents consisted of ryegrass, white and red clover and in the Herbs (HRB) treatment, these elements were augmented by various herb species (Table 2). Once during the experimental grazing seasons, the coverage degree of plant species was assessed by a grassland specialist applying the area percentage estimation according to Schechtner (1985).

Animal husbandry

A total of 111 bull calves were enrolled in this study across 2018, 2019, and 2020 (Table 3 & Online Resource Table 1). The variation in calf numbers was due to fluctuating availability.

Table 1 List of species of the two commercial seed mixtures by DSV (Deutsche Saatveredelung AG) used as treatment sown in 2016: Grass (GRS) and Herbs (HRB)

		GRS		HRB	
Species	Variety	[kg ha^{-1}]	[%]	[kg ha^{-1}]	[%]
Lolium perenne	Discus	12	39	8	25
Lolium perenne	Aston Energy	12	39	8	25
Trifolium repens	Liflex	2	6	2	6
Trifolium pratense	Taifun	5	16	3	11
Lotus corniculatus	Leo	0	0	5	15
Herb-Mix components	Countryhorse 2122	0	0	6	18
Total			100		100

Table 2 Percentage by weight of seeds in the herb-mix Countryhorse 2122 by DSV (Deutsche Saatveredelung AG) sown in 2016 in treatment Herbs (HRB)

Species	[%]
Carum carvi	18
Cichorium intybus	18
Sanguisorba officinalis	16
Foeniculum vulgare	15
Petroselinum crispum	10
Plantago lanceolata	10
Achillea millefolium	7
Pimpinella major major	3
Daucus carota carota	2
Galium mollugo	1
Total	100

The calves used in the study were of different origin (research farm or other organic farms prior to the experiment) and were subjected to different methods of milk feeding (dam, bucket, or automatic feeder). However, to avoid confounding effects related to age, body weight, breed, origin, and method of milk feeding, calves were evenly distributed to the treatments according to these characteristics. If animals displayed identical characteristics, they were assigned randomly to either group.

Over the three years of the study, twenty-eight German Holstein calves, born on the research farm, had prolonged contact with their dams, including grazing experience with them. These calves were initially housed individually with their dams for 5 to 7 d in separate calving pens. Subsequently, they were reared within a full-day dam-contact system according to the terminology of Sirovnik et al. 2020) alongside the dairy herd for 93 ± 3 d (mean ± standard deviation). Pre-experimental grazing with the dams commenced at 55 ± 23 d of age. At approximately 120 ± 25 d of age, these calves were separated from their dams, after which grazing began on the experimental paddocks.

Another 11 German Holstein calves born on the research farm were separated from their dams immediately *post partum* and were housed individually in calf hutches for 7 d. They received colostrum from their mother or another cow (frozen and thawed) via teat bottle, followed by transition milk of their mother via teat-equipped bucket feeders (Patura KG, Germany). After this period, 6 of these calves received warm whole milk from an automatic feeder (Förster-Technik GmbH, Germany) and were raised in a group setting within a calf creep with access to an outdoor area. Grazing on the experimental paddock started for these calves at an average age of 109 ± 34 d.

The remaining 5 calves born on the research farm were housed similarly to the 72 calves sourced from other organic farms, which arrived at the research farm at an average age of 27 ± 8 d. This group comprised 41 German Holstein and 31 Jersey calves, which were housed in cohorts of up to 12 animals. They were fed acidified cold whole milk via teat-equipped bucket feeders. To ensure comparable feed availability despite differences in rearing methods, calves not raised with their dams were provided with a similar quantity of milk (1,100 L over a 3-month period). This amount aligns with the findings of Barth

Table 3 Distribution of bull calves among the treatments: Grass (GRS) and Herbs (HRB) according to breed: German Holstein and Jersey. Weight and age are given for the start of the grazing period in three years

GRS							HRB				
		n	Weight [kg]		Age [d]		n	Weight [kg]		Age [d]	
			Mean	SD	Mean	SD		Mean	SD	Mean	SD
German Holstein	2018	9	115	12.9	97	10.6	9	115	10.1	98	5.6
	2019	14	148	26.3	116	29.4	15	151	29.1	105	22.1
	2020	17	145	30.1	122	20.8	16	140	29.1	120	19.8
	Total	40	139	28.5	114	24.2	40	139	29.1	110	20.4
Jersey	2018	5	98	4.2	105	7.7	5	103	7.1	104	7.5
	2019	4	103	11.7	96	3.6	4	106	7.0	96	6.1
	2020	6	103	6.7	98	6.3	7	104	4.9	97	4.6
	Total	15	101	7.4	99	7.0	16	104	5.9	99	6.6

(2020) on milk intake levels for calves raised with dam contact, although direct intake was not assessed in the current study. To ensure a smooth feed change before experimental grazing, a pre-experimental grazing with restricted initial access to pasture adjacent to their typical housing area began at an average age of 94 ± 17 d for both the bucket-fed and automatic-fed calves ($n = 83$). This introductory grazing period spanned 2 d in 2018 and 2019 but was extended to 2 weeks in 2020. Grazing on the experimental paddock began at 108 ± 17 d of age for the German Holstein calves and 99 ± 7 d for the Jersey calves, which were younger at the grazing start because they were born later than the Holstein calves in all three years of the study.

Throughout the rearing period leading up to experimental grazing, all 111 calves were offered 1.5 kg of concentrate pellets daily, consisting of 70% oats, 19% wheat, 10% peas, and 1% minerals. In addition, calves had *ad libitum* access to water, hay (grass/clover), and a TMR comprising 63.5% grass silage, 30.2% corn silage, 5.2% concentrate, and 1.2% minerals. Straw was used as bedding material in all housing conditions.

The grazing seasons during the experimental period spanned from May to October in 2018, and from April to October in 2019 and 2020. Both experimental plots were divided into 20 strips, each approximately 0.08 ha. Calves were allocated to specific strips, for 1 to 3 d until the sward reached a residual height of 4 cm measured using a raising plate meter (True North Technologies Ltd., Ireland). In case of unexpected forage shortages on pasture, the animals were provided with additional grazing strips within the same day to ensure a consistent feed supply. Furthermore, as a result of periods of drought, all animals had to be temporarily moved to two neighboring paddocks, each spanning 1.5 ha, both primarily comprised of ryegrass and clover. However, the grouping of calves remained consistent over the whole grazing period. The average duration spent in a neighboring paddock varied over the experimental period in all trial years due to a combination of diverse weather conditions and varying grazing commencement times, which were contingent upon the age of the individual calf. The individual grazing day ratio was calculated from the grazing days on the experimental paddock divided by total grazing days (which included grazing on the experimental paddock and

Table 4 Average grazing days the groups of dairy bull calves (Treatment: Grass (GRS) and Herbs (HRB)) spent on the experimental paddocks (with grass-clover or herbs sward) or on a neighboring paddock (with a grass-clover sward only) as well as days with supplementary hay feeding in three years

		2018					2019					2020				
		GRS		HRB		Total	GRS		HRB		Total	GRS		HRB		Total
		Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Pre-experimental grazing[a]	[d]					2					2					14
Grazing (experimental paddock)	[d]	95	17	94	14		62	23	55	25		77	10	77	10	
Grazing (neighboring paddock)	[d]	29	9	31	10		41	34	54	29		34	16	34	16	
Supplementary hay on pasture	[d]					30					36					15

[a] Dam-reared calves started grazing with their dams at an age of 55 ± 23 d and went into the experiment at an age of 120 ± 25 d

the adjacent paddocks, pre-experimental grazing, and grazing with the dam).

In instances of liquid fecal consistency (as determined by the fecal score based on Ireland-Perry and Stallings 1993), hay was offered in hayracks (Small Bale Feeder, Patura KG, Germany, Table 4). This measure aimed to enhance digestion by augmenting the intake of crude fiber, as published by Webb et al. (2013).

Concentrate pellets were provided daily (500 g animal^{-1}) in troughs (35 cm animal^{-1}) to ensure regular human contact to maintain safe handling of the calves. The animals had unrestricted access to mineral supplements ("Bio-Leckeimer für Rinder", Josera GmbH, Germany), as well as water troughs (through 200 L, Suevia Haiges GmbH, Germany).

Data collection

Forage samples

Forage samples were collected before the calves had access to each new strip in both treatments. Biomass was cut within the strip on four random area plots (0.5 × 0.5 m) at 4 cm above the ground level using hand shears. To obtain a representative sample, four samples were collected and pooled for each paddock representing 1 m^2 of the strip (Whalley and Hardy 2000). If calves required additional strips due to a reduced forage supply, sampling was adjusted by taking a 1 m^2 sample from each additional strip added to the pooled samples.

Total dry matter (DM) content was determined as the relative weight of the sample after drying at 60 °C in the laboratory oven (CDF-Series, Caldatrac Industrieofenbau GmbH, Germany) for 48 h. Subsequently, the samples were ground by a sample mill (Cyclotec CT 293, Foss, GmbH, Germany) using a 1 mm sieve.

The forage quality parameters were estimated using near-infrared reflectance spectroscopy (NIRS) in a NIRSystems 5000 monochromator (Foss GmbH) in the laboratory of the Christian Albrechts University (CAU), Germany. All samples were scanned twice. A mathematical evaluation of the spectra was performed using the Modified Partial Least Squares method (WinISI 3, Infrasoft International LLC, USA). Individual and functional group-specific NIRS calibrations for perennial ryegrass, legumes, and forage herb species, developed in the laboratory of the CAU, were used to predict the concentrations of crude protein (CP), ether extract (EE), crude ash (CA), neutral detergent fiber (NDF), acid detergent fiber (ADF), and enzyme-soluble organic matter (ESOM).

In addition, pooled samples were prepared for covering each calendar month on pasture for each treatment to obtain ether extract via *n*-hexane extraction. Fatty acids in the EE were derivatized to fatty acid methyl esters (FAME) according to the method described by (Schulte and Weber 1989). The FAME were separated by gas chromatography (Agilent Technologies 7890 A GC System, Agilent Technology, USA) on a capillary-column (Zebron, ZB-FAME, 60 m, 0.25 mm I.D., 0.20 µm film thickness, Phenomenex, USA) and quantified using an external standard (Supelco 37 component FAME mix, Supelco, USA).

Calf performance

The animals were weighed weekly using a mobile weighing unit (Patura KG, Germany).

We calculated the weekly weight ratio under grazing on the experimental paddock to account for variations in weight gain over the grazing period. This ratio was calculated as follows:

$$\text{Weekly weight ratio} = \frac{\text{body weight of current week}}{\text{body weight of previous week}}$$

In addition to the weekly weight ratio, we calculated daily weight gain (DWG) over the whole grazing period:

$$\text{DWG [g]} = \frac{\left(\text{weight at slaughter } [\text{kg}] - \text{ weight at grazing start } [\text{kg}]\right)}{(\text{date of slaughter} - \text{ date of grazing start})} \times 1000$$

Health monitoring

Weekly weighting of the calves included regular health assessments once a week as outlined by Roth et al. (2009), evaluating the animals' overall condition and inspecting the eyes, nose, ears, and navel for abnormalities. Additionally, animals were monitored for signs of coughing and cleanliness of the anal region. Body temperature was measured using a rectal thermometer and individual fecal samples were collected every second week. These samples were analyzed to assess fecal consistency and fecal egg counts (FEC) utilizing the McMaster flotation with quantitative microscopic examination as described by Zajac and Conboy (2012). If the FEC exceeded of 100 eggs g^{-1} feces, as applied by Bystron et al. (2018), the affected animal received treatment with an anthelmintic (Panacur Suspension 10%, Intervet GmbH, Germany) prescribed by the veterinarian (2018: 1 HRB-calf, 2019: all 18 GRS calves and 16 HRB calves, 2020: 6 GRS calves and 2 HRB calves, Online Resource Table 2).

Carcass characteristics and meat quality

From June to October, four to five calves were slaughtered on each occasion in 2018, 2019, and 2020. GRS calves were 222 ± 15 d old, HRB calves were 221 ± 13 d old. Slaughtering was conducted at a small abattoir 13 km from the research farm. The groups selected for slaughter were composed based on age and body weight.

All animals were stunned using a captive bolt, exsanguinated and then eviscerated. Subsequently, the carcasses (hot) were weighed and then chilled at 4 °C.

Dressing percentage (DP) was calculated as following:

$$\text{Dressing percentage [\%]} = \frac{\text{warm carcass weight}}{\text{weight at slaughter}} \times 100$$

One day after slaughter, carcass meat yield and distribution were graded for conformation and fat cover score. Since, to our knowledge, there was no classification scheme specifically for calves available, we referred to the European trade classification scheme – EUROP score (EU 2017).

Visual examination of the carcasses and meat sampling was always performed by the same person, unaware of the animals' identity. The *Musculus longissimus dorsi* (MLD) was cut between the 9th and 10th rib of the thoracic vertebra on the left carcass side. The surface of the meat at the 9th rib was used to visually carry out the beef marble scores using the marbling standard (score: 1–6), as reviewed by Velik (2021). To assess the size of the longissimus muscle area (LMA), photographs were taken using a camera (Ixus 105, Canon GmbH, Germany) attached to an aluminum frame (outer dimensions:15 [length] × 15 [width] × 30 [depth] cm). The frame served as a spacer between the camera and sample to standardized scale. The image processing software ImageJ 1.53e (Wayne Rasband, National Institute of Mental Health, USA) was used to measure the LMA in cm^2. The pH of the MLD was determined 24 h *post mortem* (pH_{24}) on the carcass (9th ribb) using a Portamess 911 pH meter with an insertion electrode (Knick Elektronische Messgeräte GmbH, Germany).

A "L*, a*, b*" meat color space test was done using a Chromameter (CR 200, Konica Minolta Business Solutions GmbH, Germany) on the freshly cut surface of the MLD using the parameters L*(lightness), a* (hue oriented circularly and chroma oriented radially on the green–red axis), and b* (hue oriented circularly and chroma oriented radially on the blue-yellow axis). The chromameter was calibrated to a standard white plate (Calibration Plate CR-A44). Subsequently, the samples from the MLD were taken by complete cross-section between the 8th and 10th rib, packed in plastic bags, labelled, and kept at a temperature of approximately 2 °C. Temperature was maintained by a styrofoam container during transport back to the research farm laboratory, where the meat samples were vacuum sealed and stored at −20 °C until analysis. IMF was obtained by chloroform/methanol (3:1) extraction, and the fatty acids in the IMF were derivatized to fatty acid methyl esters (FAME) according to the method of (Schulte and Weber 1989). FAME were separated by gas chromatography (Agilent Technologies 7890 A GC System, Agilent Technology GmbH, Germany) on a capillary-column (Zebron, ZB-FAME, 60 m, 0.25 mm I.D., 0.20 µm film thickness, Phenomenex, USA) and quantified using an external standard (Supelco 37 component FAME mix, Supelco, USA).

Statistical analysis

Data analyses were performed in R version 4.3.0 (R Core Team, 2023) using Bayesian linear mixed models (package blme; Dorie 2011)) with estimates calculated using parametric bootstraps. A Wald test was used for calculating the *P*-values assuming significance at $P \leq 0.05$.

Due to different breeds and ages of the animals and accordingly heterogenous body weights and weight gains, a weekly weight ratio was calculated to assess weight changes. The effects of treatment (GRS/HRB), age (weeks), the interaction of treatment and age, breed (GH/J) and the availability of feed represented by DM (kg ha^{-1} animal^{-1}) on the weekly weight ratio were estimated using a linear mixed model. The individual calf nested within treatment nested within year entered the model as a random factor to account for repeated measurements. Furthermore, a factor including the weighing week in each year and the treatment entered the model as a crossed random effect to consider the treatment specific effect of the weighing date.

Models with the same structure of fixed effects as described above were used to evaluate the effects of treatment, breed, and grazing day ratio on measurements taken at slaughter. The models were built each, with one of the following outcome variables: DWG, weight at slaughter, carcass weight, DP, meat color (L*, a*, b*), intramuscular pH_{24}, LMA, IMF, or fatty acid profiles (Table 7). In addition to breed and treatment the individual grazing day ratio were normalized and also included in the models as fixed effect. Treatment nested within year entered the models as a random factor, as grazing within treatment occurred on the same plots in each experimental year.

Visual inspections of the QQ-plots and the histograms of the model residuals were performed according to Fox (2016) to assess the model assumptions. The visual inspections indicated that an approximate normal distribution of the residuals was given in all models.

Results

At slaughter, all calves were clinically healthy. Based on regular health assessments and veterinary consultations no antibiotics were needed throughout the trial.

Swards—coverage degree, crude nutrients and fatty acids

The ground cover of herbs in HRB was 13.6%, which was lower than the seed percentages of 18% sown in 2016 (Table 5 & Online Resource Table 3). In GRS a proportion of volunteer herbs was observed (*Rumex obtusifolius*, *Taraxacum officinale* and *Ranunculus repens*), reaching a herb coverage of 2.4% in 2018, 3.7% in 2019, and 4.1% in 2020. *Lolium perenne* remained the main grass species, but volunteer grass species were found in both treatments in all trial years.

In 2019 and 2020 the coverage degree regarding legumes, grasses and herbs matched with seed percentages within the sowing of both treatments.

The mean chemical composition and mean fatty acid composition of the forage samples were similar in GRS and HRB (Table 6).

Growth rate, carcass characteristics and meat quality

Weekly weight ratios under grazing on experimental plots were not influenced by calf age, breed, plot

Table 5 Coverage degree of the sward compositions Grass (GRS) and Herbs (HRB) assessed during the grazing season in 2018–2020 (year/month) by applying the area percentage estimation according to Schechtner (1958)

GRS				HRB		
	2018/5	2019/7	2020/9	2018/5	2019/7	2020/9
	Mean	Mean	Mean	Mean	Mean	Mean
	[%]	[%]	[%]	[%]	[%]	[%]
Grasses	86.5	74.0	69.4	74.9	56.3	50.1
Herbs	2.4	3.7	4.1	13.6	17.5	18.7
Legumes	11.1	22.4	26.5	11.5	26.3	31.2
	100.0	100.0	100.0	100.0	100.0	100.0

Table 6 Dry matter (DM), chemical composition and fatty acid composition[a] of swards according to the treatments Grass (GRS) and Herbs (HRB) in each year

GRS									HRB							
	2018		2019		2020		2018–2020		2018		2019		2020		2018–2020	
n	70		34		25		129		70		34		25		129	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DM yield kg/ha animal^{-1}	57.2	71.04	121.0	72.21	70.6	47.35	76.6	72.26	61.3	55.04	117.4	73.55	98.8	108.36	83.5	76.60
DM %	28.1	7.64	23.8	4.33	23.4	4.70	26.1	6.75	26.2	6.64	22.8	4.02	26.4	12.44	25.3	7.70
Metabolizable energy (MJ/kg DM)	10.3	0.75	11.1	1.00	11.1	1.09	10.7	0.97	10.5	0.57	10.9	1.10	10.9	1.06	10.7	0.86
Neutral detergent fibre (% DM)	55.6	4.26	45.6	7.53	45.0	7.62	50.7	7.95	53.2	4.78	44.4	7.75	44.6	7.49	49.2	7.58
Acid detergent fiber (% DM)	25.5	3.13	22.1	5.62	22.5	6.37	24.0	4.86	28.8	3.35	23.3	6.35	24.6	6.74	26.5	5.61
Crude ash (% DM)	9.7	0.94	8.6	1.08	7.9	1.75	9.1	1.37	8.6	1.10	8.3	1.20	8.1	1.42	8.6	1.21
Ether extract (% DM)	3.1	0.63	2.9	0.81	2.9	1.01	3.0	0.77	3.0	0.65	2.70	0.76	2.8	0.91	2.9	0.74
Crude protein (% DM)	17.9	3.31	11.4	3.16	15.3	3.77	15.7	4.31	16.7	3.85	12.0	3.13	14.1	3.14	15.0	4.07
Enzyme-soluble organic matter (% DM)	68.8	5.74	75.0	8.10	73.2	9.25	71.3	7.63	70.4	5.52	73.8	8.86	70.9	9.77	71.4	7.54
	GRS								HRB							
	2018		2019		2020		Total		2018		2019		2020		Total	
	$n=6$		$n=7$		$n=6$		$n=19$		$n=6$		$n=7$		$n=6$		$n=19$	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
C12:0	0.2	0.28	0.5	0.48	0.3	0.31	0.3	0.37	0.2	0.21	0.5	0.53	0.2	0.20	0.3	0.38
C14:0	1.2	0.26	1.3	0.61	1.4	0.53	1.3	0.48	1.0	0.24	1.8	0.76	1.1	0.22	1.3	0.63
C15:0	0.8	0.20	0.6	0.23	0.5	0.06	0.6	0.22	0.6	0.14	0.7	0.23	0.6	0.11	0.7	0.17
C16:0	32.4	2.64	31.1	4.72	26.1	1.98	29.9	4.21	28.1	2.59	31.1	5.25	25.2	2.73	28.3	4.41
C18:0	6.3	1.60	5.1	1.25	5.0	0.89	5.5	1.35	5.3	1.21	4.8	1.32	4.4	0.40	4.9	1.08
C18:1*n*-9*c*	7.0	1.33	5.4	2.50	4.3	1.45	5.6	2.09	6.4	1.32	5.8	1.74	4.5	1.74	5.6	1.71
C18:2*n*-6*c*	17.8	2.04	17.3	2.19	22.1	6.58	18.9	4.43	19.1	1.81	20.5	1.97	22.9	5.36	20.8	3.56
C18:3*n*-3*c*	23.8	5.47	29.5	10.82	31.9	7.08	28.5	8.52	30.0	6.45	26.0	7.32	32.7	9.01	29.4	7.75
C20:0	1.1	0.31	1.0	0.76	0.9	0.30	1.0	0.50	0.7	0.31	0.9	0.20	0.9	0.39	0.9	0.29
C22:0	1.6	0.31	2.0	0.54	1.8	0.21	1.8	0.41	1.5	0.37	1.8	0.46	1.7	0.23	1.7	0.37
C22:2*n*-6	0.9	0.28	0.6	0.17	0.7	0.16	0.8	0.23	0.7	0.23	0.7	0.42	0.7	0.16	0.7	0.28
C24:0	1.2	0.21	1.3	0.35	1.3	0.13	1.3	0.25	1.1	0.22	1.2	0.28	1.3	0.17	1.2	0.23
SFA[b]	46.3	4.30	44.4	7.8	38.7	2.93	43.2	6.18	40.1	4.35	44.1	8.27	36.8	3.28	40.6	6.38
MUFAc	10.1	1.47	7.5	2.19	6.1	1.26	7.9	2.32	9.2	1.41	8.1	1.64	6.3	1.51	7.9	1.87

Table 6 (continued)

PUFA[d]	43.7	5.63	48.1	9.64	55.2	3.47	49.0	8.11	50.7	5.60	47.8	9.19	56.9	4.33	51.6	7.56
$n-6$[e]	18.7	2.10	17.9	2.09	22.8	6.46	19.7	4.36	19.8	1.91	21.2	2.14	23.6	5.28	21.5	3.58
$n-3$[f]	25.0	5.26	30.2	10.80	32.5	7.21	29.3	8.42	30.9	6.29	26.6	7.38	33.2	9.19	30.1	7.79
$n-6/n-3$ ratio[g]	0.8	0.20	0.7	0.28	0.8	0.37	0.7	0.28	0.7	0.17	0.9	0.24	0.8	0.39	0.8	0.28

[a] Percentage of fatty acid methyl ester (FAME) in mean ± standard deviation (SD) by pooled samples for covering each calendar month on pasture for each treatment

[b] Sum of saturated fatty acids: C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C21:0 + C22:0 + C24:0

[c] Sum of monounsaturated fatty acids: C16:1 + C18:1*n*−9*cis* + C20:1

[d] Sum of polyunsaturated fatty acids: C18:2*n*-6 + C18:3*n*-3*cis* + C20:5*n*-3 + C22:6*n*-3

[e] Sum of *n*-6 fatty acids: C18:2*n*-6*cis* + C22:2*n*-6

[f] Sum of *n*-3 fatty acids: C18:3*n*-3*cis* + C20:5*n*-3

[g] Quotient of the sum of *n*-3 and *n*-6 fatty acids

DM-yield or their interactions with treatment (Online Resource Table 6 and Online Resource Fig. 1).

Contrary to our hypothesis, sward composition had no effect on calf performance, carcass characteristics and meat quality. This was in contrast to breed and grazing day ratio, which had clear effects on most outcomes tested (Table 7 and Online Resource Fig. 2). Weight at slaughter, carcass weight (hot), DP and LMA were 10.2%, 16.6%, 5.1% and 10.9% higher for Holstein calves compared to Jersey calves (Table 8 and Online Resource Table 4). The muscle color (L*, a*, b*) was lighter, redder and more yellow in Holstein compared to Jersey calves. The intramuscular fat content in Holstein calves' meat was lower than in Jersey. The IMF had 14.0%, 14.1% and 15.3% higher proportions of PUFA, $n-6$ and $n-3$ in Holstein compared to Jersey, which had 1.0% and 2.6% higher proportions of SFA and MUFA. The average pH_{24} in the meat was 5.5 ± 0.20 (GH) and 5.6 ± 0.22 (Jersey).

In all calves the beef marble score was 1 (no marbling). By conformation of all calves, 74% were classified with P (Poor: Round – poorly developed, back—narrow with bones visible and shoulder – flat with bones visible) according to the European beef carcass classification system. Another 26% were classified at O (Fair: Round – average development to lacking development, back – average thickness to lacking thickness, shoulder – average development to almost flat and rump – straight profile). O was found in 35% of the German Holstein and in 3% of the Jersey calves. Fatness was scored at 1 (Low: no fat within the thoracic cavity) in 79% and at 2 (Slight: within the thoracic cavity the muscle is clearly visible between the ribs) in 21% of the calves. Score 2 was found in 25% of the German Holstein and 16% of the Jersey calves (Online Resource Table 5).

Discussion

We tested the effect of two different swards (GRS and HRB) on the calf performance, carcass characteristics and meat quality in dairy bull calves of two breeds (Holstein and Jersey) under full-time grazing conditions. Calf performances on both treatments was adequate and whilst there was no difference detected between swards, growth rate and carcass characteristics were influenced by breed and days grazing.

Table 7 Model outcome of growth rate, carcass characteristics and meat quality of dairy bull calves ($n = 111$) of two breeds (German Holstein—reference, Jersey) grazed on two swards: Grass (GRS—reference) and Herbs (HRS)

Predictor	Item		Estimates	95% CI	*P*-value[m]
Daily weight gain (DWG)	Intercept[m]	[g]	546	272 – 819	
	Treatment (HRB)		0	−83 – 83	0.999
	Breed (Jersey)		−29	−71 – 12	0.165
	Grazing day ratio (normalized)[n]		31	−9 – 71	0.130
Weight at slaughter	Intercept*	[kg]	188.6	151.0 – 226.1	
	Treatment (HRB)		1.6	−12.1 – 15.2	0.819
	Breed (Jersey)		−17.4	−23.4 – −11.3	**< 0.001**
	Grazing day ratio (normalized)[n]		8.1	2.2 – 13.9	**0.007**
Carcass weight (hot)	Intercept*	[kg]	78.1	58.6 – 97.6	
	Treatment (HRB)		0.8	−7.3 – 8.7	0.854
	Breed (Jersey)		−11.1	−14.5 – −7.7	**< 0.001**
	Grazing day ratio (normalized)[n]		4.0	0.8 – 7.3	**0.016**
Dressing percentage (DP)	Intercept*	[%]	41.1	38.5 – 43.7	
	Treatment (HRB)		0.1	−1.2 – 1.4	0.875
	Breed (Jersey)		−2.0	−2.6 – −1.3	**< 0.001**
	Grazing day ratio (normalized)[n]		0.3	−0.4 – 0.9	0.397
LMA[a]	Intercept*	[cm^2]	26.5	20.7 – 32.4	
	Treatment (HRB)		−0.7	−3.3 – 2.0	0.612
	Breed (Jersey)		−2.6	−3.7 – −1.5	**< 0.001**
	Grazing day ratio (normalized)[n]		1.8	0.8 – 2.9	**0.001**
IMF[b]	Intercept*	[%]	1.43	0.20 – 2.66	
	Treatment (HRB)		−0.09	−0.49 – 0.32	0.676
	Breed (Jersey)		0.19	0.08 – 0.31	**0.001**
	Grazing day ratio (normalized)[n]		−0.02	−0.13 – 0.09	0.761
SFA[c]	Intercept*	[%]	55.70	46.92 – 64.48	
	Treatment (HRB)		−0.26	−3.24 – 2.73	0.866
	Breed (Jersey)		0.53	−0.38 – 1.43	0.250
	Grazing day ratio (normalized)[n]		−0.38	−1.26 – 0.49	0.388
MUFA[d]	Intercept*	[%]	33.27	29.44 – 37.09	
	Treatment (HRB)		−0.72	−2.38 – 0.95	0.397
	Breed (Jersey)		0.87	0.30 – 1.43	**0.003**
	Grazing day ratio (normalized)[n]		−0.87	−1.42 – −0.32	**0.002**
PUFA[e]	Intercept*		11.03	1.03 – 21.03	
	Treatment (HRB)		0.97	−2.07 – 4.02	0.527
	Breed (Jersey)		−1.39	−2.29 – −0.49	**0.003**
	Grazing day ratio (normalized)[n]		1.26	0.39 – 2.13	**0.005**
n-6[f]	Intercept*	[%]	7.63	−0.29 – 15.55	
	Treatment (HRB)		0.75	−1.57 – 3.07	0.522
	Breed (Jersey)		−0.94	−1.61 – −0.27	**0.006**
	Grazing day ratio (normalized)[n]		1.12	0.47 – 1.76	**0.001**
n-3[g]	Intercept*	[%]	3.40	0.94 – 5.86	
	Treatment (HRB)		0.22	−0.57 – 1.01	0.578
	Breed (Jersey)		−0.45	−0.70 – −0.20	**0.001**
	Grazing day ratio (normalized)[n]		0.15	−0.10 – 0.39	0.239
n-6/*n*-3 ratio[h]	Intercept*	[%]	2.22	1.44 – 3.00	

Table 7 (continued)

Predictor	Item	Estimates	95% CI	*P*-value[m]
	Treatment (HRB)	0.06	−0.10 – 0.21	0.461
	Breed (Jersey)	0.03	−0.04 – 0.10	0.361
	Grazing day ratio (normalized)[n]	0.22	0.15 – 0.28	**< 0.001**
L*[i]	Intercept*	39.90	35.63 – 44.17	
	Treatment (HRB)	−0.23	−1.66 – 1.21	0.753
	Breed (Jersey)	−1.88	−2.64 – −1.11	**< 0.001**
	Grazing day ratio (normalized)[n]	−0.89	−1.63 – −0.15	**0.018**
a*[j]	Intercept*	15.25	12.16 – 18.33	
	Treatment (HRB)	0.09	−0.85 – 1.03	0.858
	Breed (Jersey)	−0.66	−1.15 – −0.16	**0.010**
	Grazing day ratio (normalized)[n]	0.06	−0.42 – 0.54	0.812
b*[k]	Intercept*	6.90	5.17 – 8.64	
	Treatment (HRB)	−0.07	−0.81 – 0.67	0.851
	Breed (Jersey)	−0.59	−0.93 – −0.25	**0.001**
	Grazing day ratio (normalized)[n]	−0.30	−0.63 – 0.03	0.072
pH_{24}[l]	Intercept*	5.55	5.28 – 5.82	
	Treatment (HRB)	−0.00	−0.08 – 0.08	0.922
	Breed (Jersey)	0.05	0.01 – 0.09	**0.019**
	Grazing day ratio (normalized)[n]	0.02	−0.02 – 0.06	0.266

[a]Longissimus muscle area at the 9th rib of the thoracic vertebra on the left carcass side

[b]Intramuscular fat in organic matter of longissimus muscle

Percentage of fatty acid methyl ester (FAME) of intramuscular fat in longissimus muscle

[c]Sum of saturated fatty acids: C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0

[d]Sum of monounsaturated fatty acids: C14:1 + C16:1 + C18:1*n*-9*trans* + C18:1*n*-9*cis* + C20:1

[e]Sum of polyunsaturated fatty acids: C18:2*n*-6*trans* + C18:2*n*-6*cis* + C18:3*n*-3 + C20:3*n*-6 + C20:4*n*-6 + C20:5*n*-3 + C22:6*n*-3

[f]Sum of *n*-6 fatty acids: C18:2*n*-6*trans* + C18:2*n*-6*cis* + C20:3-*n*-6 + C20:4*n*-6

[g]Sum of *n*-3 fatty acids: C18:3*n*-3 + C20:5*n*-3 + C22:6*n*-3

[h]Quotient of the sum of *n*-3 and *n*-6 fatty acids

Color at 24 h (longissimus muscle)

[i]Lightness (from 0: black to 100: white)

[j]Redness (from green if negative to red if positive)

[k]Yellowness (from blue if negative to yellow if positive)

[l]pH of the longissimus muscle 24 h *post mortem*

[m]Intercept for breed: German Holstein and treatment: GRS

[n]Grazing day ratio (normalized): This was calculated from the grazing days on the experimental paddock divided by total grazing days (which included grazing on the experimental paddock and the adjacent paddocks, pre-experimental grazing, and grazing with the dam)

[o]A Wald test was used for calculating the *P*-values and the level of significance was set at $P \leq 0.05$

Growth rate, carcass characteristics and meat quality

The results in DWG, weight at slaughter, DP and carcass characteristics of the calves in this study are not comparable with other studies where indoor-housed calves were offered an intensive diet *ad libitum*. To our knowledge, there is still a lack of studies that present results on outdoor-forage feeding systems for dairy calves. Compared to the dairy bull calves in our study, which had an average DWG of 562 g and a weight of 198 kg at 221 d at slaughter, the Holstein male calves in the study of Marti et al. (2013) reached

Table 8 Descriptive statistics of growth rate, carcass characteristics and meat quality from German Holstein and Jersey bull calves ($n=111$) grazed on two swards: Grass (GRS) and Herbs (HRS)

Daily weight gain			Weight at slaughter	Carcass weight (hot)	Dressing percentage	LMA[a]	IMF[b]	SFA[c]	MUFA[d]	PUFA[e]	*n*-6[f]	*n*-3[g]	*n*-6/*n*-3 ratio[h]	L*[i]	a*[j]	b*[k]	pH_{24}[l]
		[g]	[kg]	[kg]		[cm²]	[%]	[%]	[%]	[%]	[%]	[%]	[%]				
German Holstein	Min	−25	136.0	60.0		15.5	0.28	40.6	23.6	4.2	2.6	1.7	1.4	34.2	11.4	3.9	4.9
	1 st Quartile	442	185.0	78.8		24.8	0.74	51.1	30.1	8.4	5.6	2.8	1.9	38.4	14.6	6.6	5.4
	Median	574	206.0	87.9		29.1	1.03	55.2	32.2	12.6	8.6	4.0	2.1	41.7	15.7	7.5	5.5
	Mean	576	208.4	90.3		29.4	1.16	54.6	32.2	13.2	9.2	4.0	2.3	41.5	16.0	7.5	5.5
	SD	226.9	32.70	18.36		6.21	0.599	5.14	2.98	5.59	4.27	1.50	0.54	3.86	2.45	1.52	0.20
	3rd Quartile	700	225.5	100.8		33.6	1.40	58.0	34.1	16.7	11.4	4.9	2.4	43.9	17.2	8.3	5.6
	Max	1094	297.0	140.4		43.2	4.10	65.4	39.7	29.2	21.9	7.6	4.1	50.3	27.4	13.4	6.2
Jersey	Min	195	134.5	54.0		17.5	0.52	48.32	27.9	3.6	2.1	1.5	1.4	31.6	10.8	2.7	5.3
	1 st Quartile	412	154.0	59.2		21.6	1.19	54.0	33.6	7.5	5.1	2.3	2.0	35.6	12.6	4.8	5.4
	Median	493	166.0	62.2		23.6	1.41	55.4	34.6	9.3	6.3	2.7	2.2	37.7	13.9	6.2	5.6
	Mean	526	171.5	67.1		23.7	1.62	56.1	34.4	9.6	6.5	3.0	2.2	38.0	14.4	6.3	5.6
	SD	179.8	24.07	11.60		3.66	0.718	3.98	2.62	3.35	2.34	1.07	0.35	3.75	2.55	1.98	0.22
	3rd Quartile	599	191.3	73.6	40.9	25.6	2.05	58.2	35.9	10.6	7.1	3.6	2.3	40.8	15.8	7.7	5.7
	Max	1018	223.0	101.2	46.9	34.1	3.61	67.6	39.9	19.9	13.7	6.2	3.2	47.6	20.3	11.6	6.1

[a] Longissimus muscle area at the 9th rib of the thoracic vertebra on the left carcass side

[b] Intramuscular fat in organic matter of longissimus muscle Percentage of fatty acid methyl ester (FAME) of intramuscular fat in longissimus muscle

[c] Sum of saturated fatty acids: C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0

[d] Sum of monounsaturated fatty acids: C14:1 + C16:1 + C18:1*n*-9*trans* + C18:1*n*-9*cis* + C20:1

[e] Sum of polyunsaturated fatty acids: C18:2*n*-6*trans* + C18:2*n*-6*cis* + C18:3*n*-3 + C20:3*n*-6 + C20:4*n*-6 + C20:5*n*-3 + C22:6*n*-3

[f] Sum of *n*−6 fatty acids: C18:2*n*-6*trans* + C18:2*n*-6*cis* + C20:3*n*-6 + C20:4*n*-6

[g] Sum of *n*−3 fatty acids: C18:3*n*-3 + C20:5*n*-3 + C22:6*n*-3

[h] Quotient of the sum of *n*−3 and *n*−6 fatty acids Color at 24 h (longissimus muscle)

[i] lightness (from 0: black to 100: white)

[j] redness (from green if negative to red if positive)

[k] yellowness (from blue if negative to yellow if positive)

[l] pH of the longissimus muscle 24 h *post mortem*

a weight of 397 kg and a DWG of around 1.430 g at an age of 298 d. These animals, however, were housed indoors and fed barley straw and a high-concentrate diet *ad libitum*. Higher values in comparison to our study were also achieved in the study of Vavrišínová et al. (2019) in 10 Holstein bull calves. These were indoors and fed a TMR of maize silage, alfalfa silage, and concentrates twice daily and reached a DWG of 840 g and a weight at slaughter of around 210 kg at 263 d of age. However, feeding higher amount of concentrates in both studies could explain why our calves had comparatively lower weights and weight gains. In another study, Jersey bull calves were shown to reach around 166.2 kg and a DWG of 754 g at an age of 7.3 months (Muller et al. 2013). These calves were fed a commercial calf meal until 2 months of age, followed by a calf growth meal. In comparison, our Jersey calves reached a higher weight at slaughter around 171 kg and a lower DWG of 526 g at an age of 7.4 months.

With around 42.0%, the DP of our calves were lower compared to the high-concentrate diet fed Holstein bull calves reported by Marti et al. (2013) with a DP of 51.9% and by Vavrišínová et al. (2019) with 51%. However, again, the comparability with other studies might be limited, as calves were not fasted, although fasting status is often unreported in other studies. The filled gastrointestinal tracts lead to a mathematically lower DP compared to fasted animals. Dairy breeds typically have lower DP at the same live weight, because of higher proportions of non-carcass tissues and therefore lower carcass weights than beef breeds. These non-carcass tissues are largely intestinal and liver tissues and non-carcass fat (e.g. mesenteric and omental fat), which are removed at slaughter before the carcass is weighed (reviewed by Bown et al. 2016).

The carcass characteristics of the bull calves in the trial was homogeneous. Only the first and second grade on the scale were awarded for both fat score (low–slight) and conformation score (poor–fair) according to EUROP scheme, indicating a low level of these characteristics. However, in accordance with Nogalski et al. (2019), these fat and conformation scores correlate with age and weight. At a higher carcass weight and animal age, higher conformation classes and higher fat score can be achieved. Since our animals were slaughtered as calves, they were younger and lighter than adult cattle, which gives an indication to the lower scores in our study. Considering this, the scoring and classification system is designed for calves. However, we have chosen to use it, because, to our knowledge, no system specifically for calves exists. Since fat and conformation classification plays a secondary role in calf carcass pricing (Chever et al. 2014), the classification of carcasses with the lowest meatiness and fat tissue categories should not be overly emphasized. Marti et al. (2013) found a carcass fat cover of 1 in 17.9% and 2 in 79.5% in their Holstein bull calves. Regarding carcass conformation, 23.1% of their calves were classified as P, and 76.9% as O. The conformation of our calves was comparatively lower, with 74% at P and 26% at O, similar to the fatness score, which were 79% at 1 and 21% at 2. These values were lower than the expected carcass conformation of beef breed calves in Europe classified between classes R and U, but matched the expected fatness of less than 2 (reviewed by Domaradzki et al. 2017).

Vavrišínová et al. (2019) reported an IMF of 1.57% in the *Musculus longissimus thoracis*, while Marti et al. (2013) found 1.6% in the MLD of Holstein bull calves, which was higher compared to the 1.28% observed in our study.

No significant differences in fatty acid patterns within the IMF were found between the two treatments. Given that the fatty acid composition in beef is largely influenced by the fatty acid content of the feed and the rumen's degradation rate, as reviewed by Vahmani et al. (2017), the absence of a treatment effect with HRB may be due to the similar fatty acid profiles observed in the forage samples from both GRS and HRB treatments. However, the significantly higher *n*-3 fatty acid levels in the meat of Holstein calves compared to Jersey calves confirmed the influence of breed on fatty acid composition, as previously reviewed by Park et al. (2018).

When comparing our findings to those of Nuernberg et al. (2005), who studied adult Holstein bulls grazed on pasture, the calves of both breeds in our study reached similar fatty acid levels. Moreover, the *n*-3 fatty acid content was higher in both treatments (GRS: $3.6 \pm 1.51\%$ and HRB: $3.9 \pm 1.39\%$), particularly in Holstein calves ($4.0 \pm 1.50\%$), compared to the values reported by Nuernberg et al. (2005) for adult pastured Holstein bulls ($3.3 \pm 0.30\%$). Notably, in our study this was accomplished with minimal concentrate feed, unlike in the study of Nuernberg et al. (2005), who fed a concentrate supplemented with linseed. Such oilseeds are known to increase *n*-3 concentrations in beef IMF (reviewed by Vahmani et al. 2017). In both treatments of our study, the dominant unsaturated fatty acid was α-linolenic acid (18:3*n*-3), which may have contributed to the favorable *n*−3 concentration in the IMF of calves as young as 6–8 months at slaughter. The carcass fatty acid profile is also influenced by the total lipid content of the meat. Schumacher et al. (2022) reviewed that lean meat, with a higher proportion of phospholipid in muscle cell membranes and hence PUFA, as observed in the calves of the present study, will have less triglycerides and hence SFA, rather than meat with a high degree of marbling or subcutaneous fat.

Beef meat color is a crucial attribute for visual appeal and consumer acceptance. Darker meat colors are generally associated with less favorable meat conditions, as reviewed by Hughes et al. (2014). Priolo et al. (2001) reviewed that meat produced from pasture feeding tends to be darker than meat from cattle raised on concentrates. A similar tendency was also observed in calves by Ripoll et al. (2013), who found that the meat of pasture-raised suckler calves was darker (L* = 38.0–40.0) than that of both suckled, supplemented calves and weaned calves finished on concentrates (L* = 42.0–44.0) when measured 24 h *post mortem*. Priolo et al. (2001) named several factors that may contribute to this difference, including carcass fatness, pH value, animal age, carcass weight, intramuscular fat, and myoglobin concentration. Varnam and Sutherland (1995) hypothesized that grass-fed animals have higher muscle myoglobin levels due to the increased physical activity compared to animals kept indoors and fed concentrates. Muscles from grass-fed cattle contain nearly twice as much myoglobin as those from grain-fed cattle (Apaoblaza et al. 2020). Apaoblaza et al. (2020) assigned this as indication that lean beef from grass-fed cattle has higher levels of enzymes associated with oxidative metabolism, suggesting that darker color in grass-fed cattle may result from increased oxidative activity. Scheeder (2015) stated that, the L* value for veal calves in Switzerland aged between 160 d and eight months should exceed 42.0 to meet industry recommendations. The L*value in our study, however, was lower. Similarly, Marti et al. (2013) reported an L* value of 36.1, while Vavrišínová et al. (2019) found a higher L* value of 42.1 in Holstein bull calves.

The pH_{24} values measured in this study were consistent across all calves, averaging 5.5 ± 0.20, which aligns with the findings of Marti et al. (2013) with a pH_{24} of 5.5, and Vavrišínová et al. (2019) with a value of 6.0. These results fall within the acceptable pH_{24} range for veal (5.4 to 5.7), as reviewed by Domaradzki et al. (2017). An acceptable pH range indicates proper *post mortem* glycolysis, but also indirectly indicates correct handling of the calves before slaughter (Ripoll et al. 2013).

Study limitations

In this study, data collection was conducted in a long-term trial over three years on pasture. Although we tried to keep all experimental conditions as stable as possible, we were not able to influence weather conditions and availability of calves that could be included into the study sample. This resulted in some imbalances in the data set.

For example, we had to purchase additional calves to meet the minimum group size requirement and could not only use the calves born from the research farm´s dairy herd. The final number of animals was based on the supply and availability of the calves.

Also, the unscheduled forage scarcity in the paddock, which led to a reduction in treatment exposure along with partial hay supplementation, were limitations of our study. Despite these constraints, 75% of the calves spent over half of their total grazing time on the experimental plots, and this period was explicitly considered in the models. However, there is currently no data indicating how much grazing time is necessary for the effects of different swards to become evident in the growth rate, carcass characteristics and meat quality of dairy calves. Thus, the missing difference between the treatment groups may be caused by a period of grazing on the specific plots that was too short. However, many farmers are facing similar challenges due to limited land availability or changing climatic conditions.

Conclusion

Our results indicate that grazing is a suitable and healthy approach for growing dairy bull calves yielding a favorable fatty acid profile in veal. This profile is characterized by increased polyunsaturated fatty acid percentages and decreased monounsaturated fatty acid percentages and depends on breed. However, the effect of different sward compositions could not be confirmed under the conditions of our study and needs to be further investigated.

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Data availability Authors used or generated research data in this study.

Declarations

Conflict of interest The authors declare no competing interests.

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