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# Feeding efficiency and behaviour of growing bulls from the main Italian dual-purpose breeds

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**ABSTRACT**

To characterise the main Italian dual-purpose breeds in terms of feed efficiency and behaviour, the dry matter intakes (DMI) of 890 young bulls were collected using automatic feeding systems in two Italian genetic centres. In Experiment 1, Italian Simmental (IS), Rendena (RE) and Alpine Grey (AG) young bulls were fed total mixed ration for 46 days. In Experiment 2, Valdostana Red Pied (VR) and Black Pied and Chestnut (VB) young bulls were fed hay and concentrate for 60 days. The IS and RE bulls grew faster than AG (1.6 vs. 1.3 kg/d, $p < .01$). The DMI was highest for IS and lowest for AG while all breeds had similar values for DMI expressed as relative to body weight. Overall, RE and AG bulls were more efficient than IS. Regarding feeding behaviour, the number of feeding events for IS and AG was higher than for RE, while the feeding time was not different between breeds. The IS bulls showed a higher value of feeding rate (FR) than RE and AG (98.2 vs. 83.1–86.5 g DM/min, $p < .01$). Overall AG breed, despite its high feeding activity, was particularly efficient. In addition, efficient animals showed a low FR compared to inefficient ones. In Experiment 2, VR and VB strains were quite similar in terms of growth capacity but VR was more efficient despite its higher daily activity. In conclusion, dual-purpose breeds can reach notable growths and feed efficiencies and FR is well related to feed efficiency.

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Dual-purpose breed; growing bull; residual feed intake; residual concentrate intake; feeding behaviour

**HIGHLIGHTS**

- Rendena and Alpine Grey bulls are slightly more efficient than Italian Simmental bulls
- Valdostana strains differ for feed efficiency but not for growth capacity
- Feeding rate is a useful behaviour trait to consider in the study of feed efficiency

## Introduction

The cattle dairy system in Italy is rich in biodiversity, with some important specialised dairy breeds in the lowlands and many dual-purpose breeds in mountain areas (Sturaro et al. 2013).

Alpine Grey (AG) is a small-medium-sized Alpine breed, widespread in the Austrian and Italian Tyrol where it is raised in small herds with summer transhumance in high mountain pastures (Mancin et al. 2021). Rendena (RE) is a limited-spread breed, native to the Province of Trento, where it is raised in small Alpine farms. It is also well adapted to lowland farms where it reaches good milk yields (Guzzo et al. 2018). Italian Simmental (IS) stands out among the Italian dual-purpose breeds for its wide diffusion and high production. It is a cosmopolitan breed, as it belongs to the Simmental strain, which is raised with different breeding systems from the alpine pastures to the large farms of the Po Valley (Romanzin et al. 2013). The Valdostana breed is a small-sized Alpine breed, widely distributed in the homonymous mountain region, and is the only breed that can be used to produce the well-known Fontina cheese. Within this breed, two strains are recognised: Valdostana Red Pied (VR) and Valdostana Black Pied and Chestnut (VB; Mazza et al. 2015; Strillacci et al. 2020).

The characteristic type of breeding of these animals leads to important benefits in the Alpine areas, both social and ecosystemic (local products, landscape, biodiversity, animal welfare, etc.), with notable cultural, environmental, and, ultimately, tourist implications (Battaglini et al. 2014; Zuliani et al. 2017; Gianelle et al. 2018). Interest in the conservation of dual-purpose breeds has promoted the development of focused breeding programs, in order to preserve

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resilience and adaptability to different husbandry environments. In addition to production (meat and milk), feed efficiency has become increasingly important, not only for its economic implications (e.g. impact on costs per unit of animal product) but also for its environmental relevance (e.g. reducing methane emissions; Madilindi et al. 2022).

The most common index used to state the level of feed efficiency is residual feed intake (RFI), which results from the difference between actual dry matter intake (DMI) and the DMI predicted from body size (e.g. live weight) and performance (e.g. growth or milk yield). Considering comparable production levels, efficient animals (negative RFI values) are characterised by lower feed intake and reduced emissions compared to inefficient ones.

Measurement of RFI on growing bulls selected for reproductive purposes is widely used as it has a fairly good heritability (0.33 ± 0.01, with a range of 0.07–0.62; Berry and Crowley 2012) and in dairy breeds the transmission of the trait to the female progeny is expected to improve milk yield efficiency. However, the effects of the selection of this character on other traits (milk composition, fertility, health) are under study to avoid any undesirable correlated response (e.g. insufficient fat reserves to contrast negative energy balance in early lactation of dairy cows; Madilindi et al. 2022).

Manca et al. (2021) proposed a new feed efficiency indicator for cattle that is only based on concentrate intake, named residual concentrate intake (RCI). Despite the drawback of not accounting for forage intake, this index has the significant benefit of making it easier to monitor individual consumption using new feeding equipment (e.g. auto feeders with identification systems).

Feed efficiency is a multifactorial trait, with different factors influencing the divergences between animals (e.g. digestibility, rumen parameters, body composition; Cantalapiedra-Hijar et al. 2018). Among them, feeding behaviour probably makes an important contribution also considering the significant differences in DMI between efficient and inefficient cattle (Cantalapiedra-Hijar et al. 2018; Fregulia et al. 2021). In literature, only a few studies compared different dual-purpose cattle breeds, among them Cozzi et al. (2009) monitored, with direct but partial observation (scan-sampling technique), feeding behaviour and diet selection without finding differences between breeds.

This study aims to compare feeding behaviour, feed efficiency and performance traits of growing bulls from the main Italian dual-purpose breeds during performance tests. Evaluation of the relationship between feeding behaviour traits and performance metrics was given special attention.

## Materials and methods

In this study, body weight (BW) and DMI data from performance tests conducted from 2018 to 2021 at the Italian genetic centres of Fiume Veneto (PN, Italy; for IS, RE and AG; Experiment 1) and Gressan (AO, Italy; for VR and VB; Experiment 2) were used.

### *Animals, housing and animal management (Experiment 1)*

Measures for DMI and feed efficiency were performed at the Fiume Veneto genetic centre and have been reported in detail previously by Romanzin et al. (2021), so only the main points will be briefly described in this study. Calves born from the best sires and cows of the Italian populations of IS, AG and RE were selected by the respective National Breeders Associations, transferred to the genetic centre, and subjected to growth performance test. Calves arrived at the centre at the age of about 30 days, were fed a milk replacer until weaning at the age of about 4 months, and then were allocated to multiple pens of six subjects. After an adaptation period of about 30 days, the performance test began and continued until the bulls were 12 months old.

During the performance test, at the age of about 9 months, bulls from the same pen were moved to a pen in the same barn equipped for the RFI test, which lasted 46 days on average. The equipment for monitoring intake and feeding behaviour was composed of two electronic troughs (RIC system; Hokofarm Group, Marknesse, The Netherlands; Chapinal et al. 2007), which allows the identification of bulls through their ear tags and the measurement of weight changes of the ration in the feed bunk at each feeding event (FE). During each day of test the number of FE (FEn) and the length of each FE (FEd) were recorded and the missing events number (MEn) and length (MEd) were considered whenever a bull entered the trough without causing a change in the feed weight.

Animals were fed with a total mixed ration (TMR) prepared daily and distributed twice a day ad libitum in the electronic troughs. Every 42 days, after a 12-h period of feed restriction, bulls were weighed in the morning. The effective length of the RFI test for each bull was calculated excluding the first 5 days (adaptation time) and days per subject with DMI falling into the highest or lowest 1%.

### Animals, housing and animal management (Experiment 2)

Every spring, the National Breeders Association of Valdostana breed transfers calves born in winter from the best sires and cows of both strains (VR and VB) to the genetic centre of Gressan to undergo further growth performance tests. Calves of this experiment arrived at the centre at an age of about 30 days in homogenous groups of 20–30 animals, during three subsequent months. After a 30-days adjustment period, the performance test started, and it lasted until the bulls were 12 months old. They were fed a milk substitute until weaning at the age of 4 months. The feed control test was run over this time for an average of 60 days.

The bulls were equipped with a pedometer to measure the activity time and divided into pens of six-eight animals. All the pens were set up with an automatic feeder (AfiFarm system, SAE Afikim, Kibbutz Afikim, Israel) for the individual administration of concentrate ad libitum, whereas the meadow hay was provided daily per each pen in an amount of 1.86 kg DM/animal/d on average. The residue was assumed to be equal to zero. The feeding program adopted during the feed intake control of bulls was based on a specific fibrous compound feed with minimal amounts of hay (∼20% of total DMI) and was specifically studied to allow the calculation of the RCI index as proposed by Manca et al. (2021). Bulls were weighed at the beginning and end of the feeding period, in the morning after a period of feeding restriction of about 12 h.

### Chemical analysis and prediction of nutritive value of diets

In Experiment 1, TMR was sampled weekly and samples were predried at 60 °C for 48 h and then milled through a 1-mm screen (Pulverisette; Fritsch, Idar-Oberstein, Germany). Analysis of residual DM was performed by heating at 105 °C for 3 h (method 930.15; AOAC 2000). Ash was measured by incineration at 550 °C for 2 h (method 942.05; AOAC 2000) and neutral detergent fibre (NDF) was determined using a fibre analyser (Ankom II Fibre Analyser; Ankom Technology Corporation, Fairport, NY) following the procedure of Van Soest et al. (1991) without correction for residual ash. Finally, N content was determined using the Kjeldahl method (method 976.05; AOAC 2000) and the crude protein (CP) content as N*6,25.

In Experiment 2, concentrate and hay were sampled during the feeding control period of each group of bulls and were analysed with the same methods as Experiment 1.

The energy and protein nutritional values of both rations were calculated according to the French evaluating system (INRA 2018) adopting tabulated values of UFV (fattening feed unit for maintenance and growth) and intestinal digestible protein (PDI). The INRA protein system sums the by-pass digestible protein with estimated microbial protein synthesis, according to fermentable energy and rumen degradable protein, to predict total intestinal digestible protein and rumen protein balance.

### Calculations

Three weights of each bull were used in Experiment 1 with the condition that the intermediate weight was taken during the RFI period. The BW and dates of measurements were used to obtain a linear regression equation for each bull, which was then used to estimate the average daily gain (ADG, as a slope of regression) as well the initial and final BWs of all bulls. Feed to gain ratio (F:G) value was obtained as the ratio between the DMI and the ADG. Concerning feeding behaviour, FEn and FEd data and daily DMI allowed calculation of feeding time (FT), the quantity of DMI of each feeding event (DMI/FE), and feeding rate (FR) as the ratio between DMI/FE and FEd for each bull.

In Experiment 1, RFI was computed as the difference between actual DMI and expected DMI (eDMI) from the linear regression of mean DMI on mid-test $BW^{0.75}$ and ADG, as described by Koch et al. (1963):

$$eDMI = \alpha + \beta(ADG) + \gamma(BW^{0.75}) + \varepsilon$$

where $\alpha$, $\beta$ and $\gamma$ are parameters of the regression equation and $\varepsilon$ is the error term.

In Experiment 2, the BWs data were used to obtain the ADG of each animal. The RCI was calculated as the difference between actual concentrate DMI (cDMI) and expected concentrate DMI (ecDMI), which was estimated by using the same linear regression model of Experiment 1.

Enteric methane production ($CH_4$) and nitrogen (N) excretions were also calculated in both experiments. $CH_4$ was predicted using the following equation (adapted from IPCC 2006):

$$CH_4\ (g/d) = \frac{DMI \times 18.45 \times (6.5 \times 10)}{55.65}$$

where 18.45 is the average dietary gross energy content (MJ/kg DM), 6.5 is the extent to which gross feed energy is converted to $CH_4$ (%), and 55.65 is the energy content of $CH_4$ (MJ/kg$CH_4$).

The N intake was calculated from the CP content of the diet and the DMI, and N excretion in urine (NU) and faeces (NF) was estimated using prediction equations for beef cattle (Dong et al. 2014):

$$\text{NU (g/d)} = -14.12 + 0.51 \times \text{N intake (g/d)} \ (\text{RMSE} \pm 4.07)$$

$$\text{NF (g/d)} = 15.82 + 0.20 \times \text{N intake (g/d)} \ (\text{RMSE} \pm 2.68)$$

## Statistical analysis

All statistical analyses were performed using SAS (SAS Institute 2019, release 9.4) and data were checked for normal distribution by using UNIVARIATE procedure.

In Experiment 1, BW and age of bulls were statistically analysed as a factorial design using the following model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$$

where $\mu$ is the overall mean, $\alpha_i$ is the fixed effect of the breed ($i = 1,3$), $\beta_j$ is the random effect (block) of the cycle (group of animals moved simultaneously at the RFI test) ($j = 1,57$) and $\varepsilon_{ijk}$ is the random error. Performance data, predicted emissions and feeding behaviour of bulls were covariated for initial BW and analysed with the same model.

Correlations between performance (DMI, RFI and F:G) and feeding behaviour traits of all bulls in Experiment 1 were also calculated using the CORR procedure. After a visual examination of the data using the GPLOT procedure, the two variables with the highest correlation coefficient (DMI/FE and FEn) were fitted using the following nonlinear model and the NLIN procedure:

$$Y_i = A \times x_i^{-b}$$

where $Y_i$ and $x_i$ are the average DMI/FE and the average FEn of each bull in Experiment 1 ($i = 1,640$) respectively, while $A$ and $b$ are coefficients.

To study the feeding behaviour throughout the day in the three breeds DMI, FT and FR ($y$) were analysed with the following model and the GLM procedure:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

where $\mu$ is the overall mean, $\alpha_i$ is a fixed effect of breed ($i = 1,3$), $\beta_j$ is the random effect of time (in hours) throughout the day ($J = 1,24$), $(\alpha\beta)_{ij}$ is the fixed interaction effect of breed and hour and $\varepsilon_{ijk}$ is the random error. The PDIFF option was used to evaluate pairwise comparisons between breeds' means, which were considered to be significantly different when $p < .01$.

In Experiment 2, BW and ages of bulls were statistically analysed with the same model as Experiment 1, whereas performance data, feed efficiency, predicted emissions and measure of activity with the following model:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k + \varepsilon_{ijkl}$$

where $\mu$ is the overall mean, $\alpha_i$ is the random effect (block) of the cycle ($i = 1,3$), $\beta_j$ is the year of control ($j = 1,4$), $(\alpha\beta)_{ij}$ is the interaction between cycle and year of control, $\gamma_k$ is the fixed effect of the Valdostana strains ($k = 1,2$) and $\varepsilon_{ijkl}$ is the random error.

# Results

## Diets

The two diets (Table 1) were different in terms of ingredient composition, since the corn silage and straw represented one-third of the DM in Experiment 1, while these ingredients were not used in Experiment 2 where the fibre was mainly supplied by meadow hay. In addition, soybean meal in Experiment 2 assured most of the protein intake, while in Experiment 1 different meals were used, such as soybean, sunflower, and rapeseed meals. According to the differences in diet formula, NDF was quite higher in Experiment 1 due to the important contribution given by forages. In general, both diets would have supported adequate ruminal function in terms of rumination and buffering capacity. CP was moderately different between diets, with a head in Experiment 2 compared to Experiment 1 (14.1% vs. 13.5% DM). Based on the INRA (2018) evaluating system the concentration of PDI was adequate, with an expected slight imbalance at rumen level (<5%). Overall, the energetic concentration of both diets was similar (0.96 vs. 0.94 UFV/kg DM).

## Experiment 1

Results of performance, feed efficiency, predicted emissions and feeding behaviour of the dual-purpose breeds considered are shown in Table 2.

The IS and RE bulls grew faster than AG, but the growth relative to BW was higher for RE than IS and AG. The DMI was highest for IS, intermediate for RE, and lowest for AG (10.2, 9.6 and 8.7 kg DM/d respectively, $p < .01$), while the intake expressed relative to BW was similar for all three breeds. Overall, RE and AG

**Table 1.** Ingredients, chemical composition, and nutritive values of the rations fed to the growing bulls in the two feed efficiency tests, RFI test (TMR ad libitum) and RCI test (restricted use of forage and concentrate ad libitum).

| | Experiment 1 RFI test | Experiment 2 RCI test |
|---|---|---|
| Ingredient, % DM | | |
| Ground corn | 28.2 | 32.3 |
| Barley | 5.8 | – |
| Wheat bran | 5.8 | 12.9 |
| Soybean meal | 1.9 | 11.3 |
| Sunflower and rapeseed meals | 14.6 | – |
| Dried beet pulp | 5.8 | 6.5 |
| Corn silage | 27.2 | – |
| Wheat straw | 8.7 | – |
| Meadow hay | – | 30.6 |
| Mineral and vitamin mix | 1.9 | 6.5 |
| Chemical composition | | |
| DM (%) | 61.8 | 90.0 |
| NDF (% DM) | 37.1 | 30.8 |
| CP (% DM) | 13.5 | 14.1 |
| Ash (% DM) | 6.1 | 9.2 |
| Nutritive values | | |
| UFV (UFV/kg DM) | 0.96 | 0.94 |
| PDI (g/kg DM) | 88.2 | 98.4 |
| Rumen protein balance (g/kg DM) | 0.60 | 4.8 |

Vitamin and mineral mix (in 1 kg) (Experiment 1): vitamin A, 100,000 IU; vitamin $D_3$, 12,000 IU; vitamin E, 450 mg; choline chloride, 1000 mg; $FeCO_3$, 1076 mg; KI, 39 mg; $Ca(IO_3)_2$, 21.6 mg; $Mn_2O_3$, 1161 mg; $CuSO_4{\cdot}5H_2O$, 275 mg; ZnO, 620 mg; $ZnSO_4$, 2055 mg; $Na_2SeO_3$, 3.1 mg; *S. Cerevisiae* MUCL 39885, 120 * $10^9$ CFU; *S. Cerevisiae* MUCL 39885, 120 * $10^9$ CFU.
Vitamin and mineral (in 1 kg) (Experiment 2): vitamin A, 250,000 IU; vitamin $D_3$, 25,000 IU; vitamin E, 2000 mg; vitamin B1 100 mg; nicotinic acid 10,000 mg; $Ca(IO_3)_2$, 30.0 mg; $Mn_2O_3$, 1800 mg; $CuSO_4{\cdot}5H_2O$, 600 mg; ZnO, 4350 mg; Selenomethionine 2250 mg, *S. Cerevisiae* CNCM I-1077 15 * $10^9$ CFU.
CP, crude protein; DM, dry matter; NDF, neutral detergent fibre; RFI, residual feed intake; RCI, residual concentrate intake; UFV, fattening feed unit for maintenance and growth for ruminants (1 UFV equals to 1760 kcal of net energy for maintenance and growth, INRA 2018), PDI, proteins truly digestible in the intestine (INRA 2018).

bulls were more efficient than IS in terms of RFI (–0.33 and –0.36 vs. +0.09 kg DM/d, $p < .01$).

Emissions of $CH_4$ and N were significantly different between breeds. IS bulls had the highest values (220.5, 98.3 and 59.9 g/d of $CH_4$, NU and NF, respectively), while AG bulls had the lowest values ($p < .01$, at about 15%, 16% and 11%, respectively less than IS), while the RE bulls always had intermediate values among the other breeds.

Regarding feeding behaviour, the number of FEn for IS and AG (51 per day, on average) was significantly higher ($p < .01$) than in RE (45 per day). The total FT, on the other hand, was no different between the breeds (114 min/d on average). The average FEd had no different duration between the three breeds (2.6 min/event) but resulted in a higher ($p < .01$) DMI per visit for IS and RE (0.23 kg DM/event) compared to AG (0.19 kg DM/event). In terms of FR, IS bulls showed a significantly higher rate than RE and AG (98.2 vs. 83.1–86.5 g DM/min, $p < .01$). AG bulls had a higher

**Table 2.** Growth, feed efficiency, predicted emissions and feeding behaviour of growing bulls in RFI test.

| | Italian dual-purpose breeds | | | |
|---|---|---|---|---|
| | IS | RE | AG | RMSE |
| *n* | 495 | 69 | 76 | – |
| BW and age | | | | |
| Initial age (d) | 281.1 | 283.4 | 281.1 | 10.57 |
| Initial BW (kg) | $369.4^A$ | $349.2^B$ | $324.1^C$ | 42.02 |
| Final age (d) | 326.9 | 328.1 | 327.2 | 10.53 |
| Final BW (kg) | $456.6^A$ | $433.4^B$ | $397.4^C$ | 44.09 |
| Mid-test $BW^{0.75}$ (kg) | $91.5^A$ | $87.8^B$ | $82.7^C$ | 7.12 |
| Performance | | | | |
| ADG (g/d) | $1549^A$ | $1606^A$ | $1317^B$ | 231.1 |
| ADG (% BW) | $0.38^B$ | $0.41^A$ | $0.37^B$ | 0.052 |
| DMI (kg DM/d) | $10.20^A$ | $9.57^B$ | $8.71^C$ | 0.749 |
| DMI (% BW) | 2.49 | 2.47 | 2.44 | 0.174 |
| F:G (kg DM/kg) | $6.76^A$ | $6.16^B$ | $6.89^A$ | 1.083 |
| RFI (kg DM/d) | $0.09^A$ | $-0.33^B$ | $-0.36^B$ | 0.655 |
| Emissions | | | | |
| $CH_4$ (g/d) | $220.5^A$ | $206.9^B$ | $188.3^C$ | 16.18 |
| NU (g/d) | $98.3^A$ | $90.3^B$ | $82.1^C$ | 8.27 |
| NF (g/d) | $59.9^A$ | $56.8^B$ | $53.5^C$ | 3.24 |
| Feeding behaviour | | | | |
| FEn (number/d) | $50.24^A$ | $44.92^B$ | $51.76^A$ | 14.579 |
| FT (min/d) | 110.44 | 117.65 | 112.64 | 25.209 |
| FEd (min/event) | 2.50 | 2.92 | 2.49 | 1.137 |
| DMI/FE (kg DM/event) | $0.23^A$ | $0.23^A$ | $0.19^B$ | 0.067 |
| FR (g DM/min) | $98.23^A$ | $86.47^B$ | $83.05^B$ | 21.742 |
| MEn (number/d) | $8.68^B$ | $7.71^B$ | $11.42^A$ | 4.467 |
| MEt (min/d) | 6.72 | 6.71 | 7.42 | 4.771 |
| MEd (min/MEv) | 0.84 | 0.92 | 0.74 | 0.561 |

$^{A,B,C}$means in the same row with different superscript are significantly different ($p < .01$).
ADG, average daily gain; AG, Alpine Grey; BW, body weight; $BW^{0.75}$, metabolic body weight; $CH_4$, methane; DMI, dry matter intake; DMI/FE, DMI per feeding event; F:G, feed to gain ratio; FEd, duration of feeding event; FEn, number of feeding events; FR, feeding rate; FT, feeding time; IS, Italian Simmental; MEd, missing event duration; MEn, number of missing events; MEt, time of missing events; NU, N urinary; NF, N faecal; RE, Rendena; RMSE, residual mean square error; RFI, residual feed intake.

MEn (11 per day) compared to IS and RE (on average 8 per day, $p < .01$) but MEd was similar between breeds (around 7 min/ME).

Pearson correlation coefficients between performance and feeding behaviour traits of the breeds considered in Experiment 1 are presented in Table 3. While there were strong correlations across behaviour traits, there were also significant but weak correlations between behaviour and performance traits. Most notably DMI/FE had a positive correlation with FEd (+0.80) and a negative correlation with FEn (–0.87), meanwhile, the correlation between FEd and FEn was negative (–0.77). In Figure 1, the graphic representation of the exponential fitting between DMI/FE and daily FEn is reported ($R^2$=0.96). A similar outcome was obtained for the relationship between FEd and FEn (the graph has not been included in this article).

A comparison between the three breeds in terms of DMI, FT and FR throughout hourly intervals of the day (e.g. hour 1 is equal to the interval between midnight and one o'clock) is graphically reported in Figure 2. Two feeding activity peaks match to the two moments of the day when the TMR was delivered, while there was a sharp decline of DMI during nocturne hours. IS e RE showed greater DMI than AG ($p < .01$) at 09, 10, 11, 18, e 19 h. FT had a similar trend but with less marked peaks and also without significant differences between breeds probably due to the high data variability (Figure 3). DMI and FT were divided to get FR (Figure 4), which was always a higher for IS compared to the other two breeds but reached the statistical significance only at 09 and 10 h.

### *Experiment 2*

The main results of performance, feed efficiency, predicted emissions, and measure of activity obtained in Experiment 2 on two Valdostana strains are shown in Table 4.

The VB bulls had a numerically higher ADG than VR (0.89 vs. 0.82 kg/d), which became significant when expressed as a percentage of BW. However, cDMI was also slightly higher in VB than in VR (4.28 vs. 4.10 kg DM/d, $p < .01$), resulting in a similar F:G ratio between strains (6.19 vs. 5.47 kg DM/kg, respectively, for VR and VB). The VR bulls had a neutral mean RCI value while the VB bulls were slightly inefficient (+0.13 kg DM/d). Emissions of $CH_4$ and N were always slightly higher in VB than in VR (+2%–4% approximately). The activity index, recorded by the pedometers, was higher in VR than in VB (+7%, $p < .01$).

## Discussion

In general, the three dual-purpose breeds considered in Experiment 1 differ in size and, even if in a less

**Table 3.** Pearson's correlation (*r* values) between performance and feeding behaviour traits in RFI test.

| Traits (unit) | DMI | RFI | F:G | FEn | DMI/FE | FR | FEd | MEn |
|---|---|---|---|---|---|---|---|---|
| Performance | | | | | | | | |
| DMI (kg DM/d) | | | | | | | | |
| RFI (kg DM/d) | 0.69* | | | | | | | |
| F:G (kg DM/kg) | 0.15* | 0.38* | | | | | | |
| Feeding behaviour | | | | | | | | |
| FEn (number/d) | 0.04 | 0.22* | 0.01 | | | | | |
| DMI/FE (kg DM) | 0.28* | 0.03 | 0.04 | −0.87* | | | | |
| FR (g DM/min) | 0.33* | 0.24* | 0.25* | 0.36* | −0.20* | | | |
| FEd (min/event) | −0.02 | −0.14* | −0.13 | −0.77* | 0.80* | −0.62* | | |
| MEn (number/d) | −0.19* | 0.08 | −0.07 | 0.53* | −0.49* | −0.06 | −0.30* | |

*$p < .01$.
DMI, dry matter intake; DMI/FE, DMI per feeding event; RFI, residual feed intake; F:G, feed to gain ratio; FEd, duration of feeding event; FEn, number of feeding events; FR, feeding rate; MEn, number of missing events.

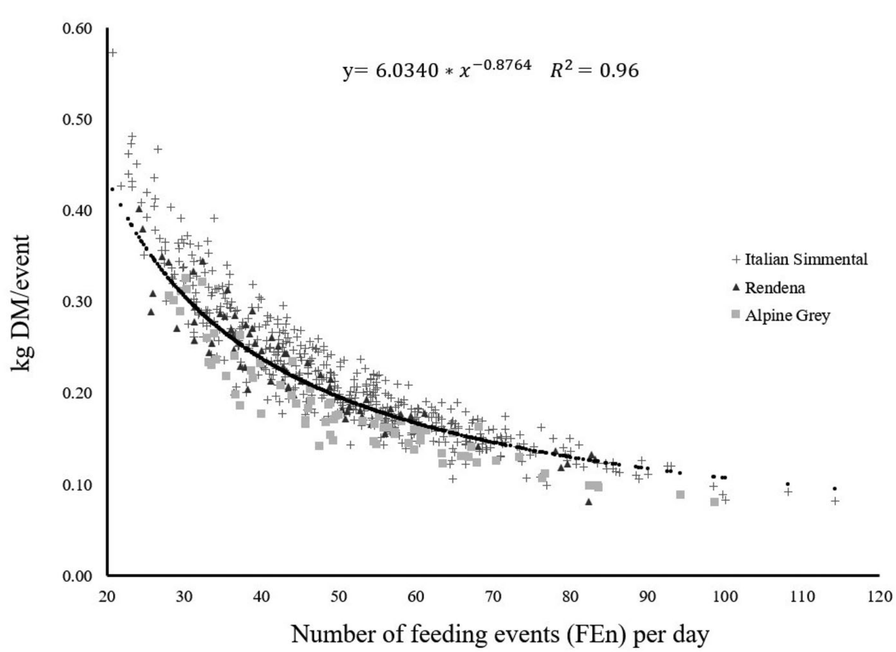


**Figure 1.** Average feed intake (kg DM) per feeding event (*y*) plotted against the daily average number of events (*x*) of each bull ($i = 640$) in RFI (residual feed intake) test and interpolation of the data with a nonlinear model ($Y_i = A * x_i^{-b}$).

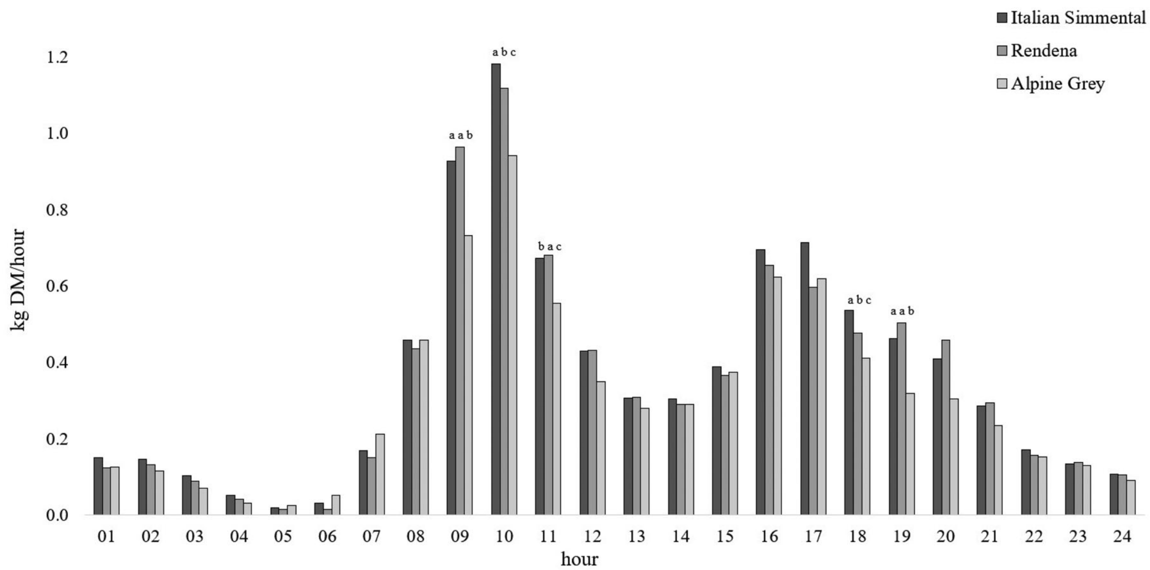


**Figure 2.** Feed intake (kg DM) at 1-h intervals throughout the day in RFI (residual feed intake) test (different letters over the bars within each hour of the day denote statistical differences among breeds, $p < .01$; RMSE = 0.517).

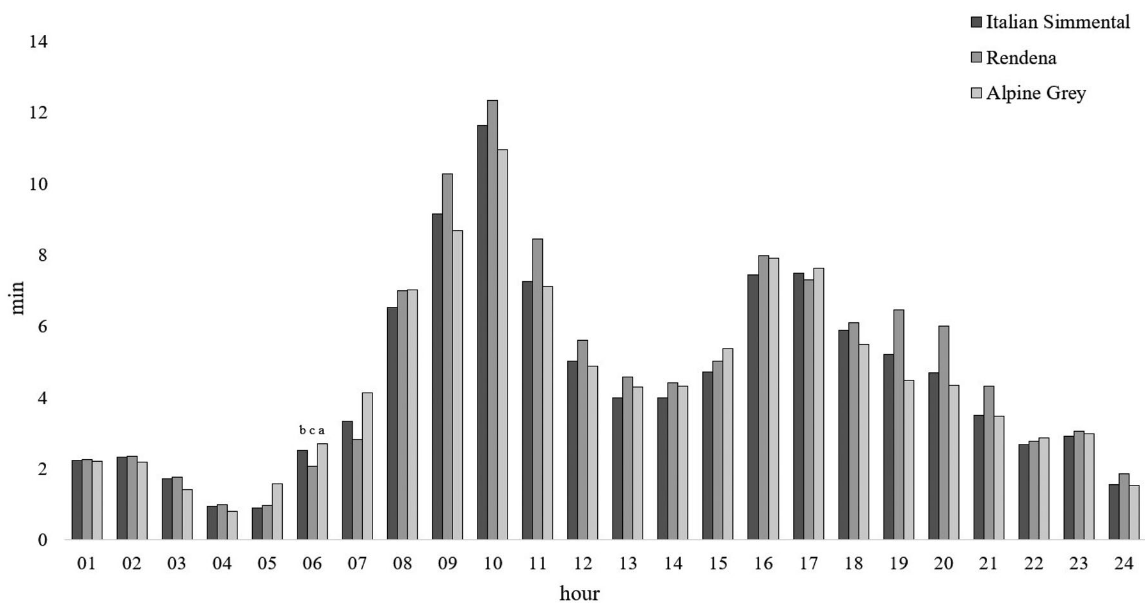


**Figure 3.** Feeding time (min) at 1-h intervals throughout the day in RFI (residual feed intake) test (different letters over the bars within each hour of the day denote statistical differences among breeds, $p < .01$; RMSE = 11.882).

pronounced way, in the production capacity (both in terms of milk and meat) as described by Cozzi et al. (2009). However, the juvenile phase considered in this trial reduces BW and ADG differences, in particular between IS and RE. The growth performances of IS confirmed the preliminary results discussed in Romanzin et al. (2021) in a trial on a more limited number of animals. RE had shown excellent growth performance with rather low consumption even compared to the few data that can be found in the literature (Corazzin et al. 2018; Guzzo et al. 2019). A separate discussion must certainly be made for AG, a breed with small size but good muscularity that had shown high growth and very low feed consumption. In a study performed with Italian Alpine cattle breeds fed a diet similar to that of our study, Cozzi et al. (2009) obtained lower values of DMI and ADG. This is likely due to the genetic progress in the last decade and the larger growth phase considered in that trial. However, the breed comparison reflected what was found in this study: IS had higher DMI and ADG than AG, while RE had intermediate values. Our study

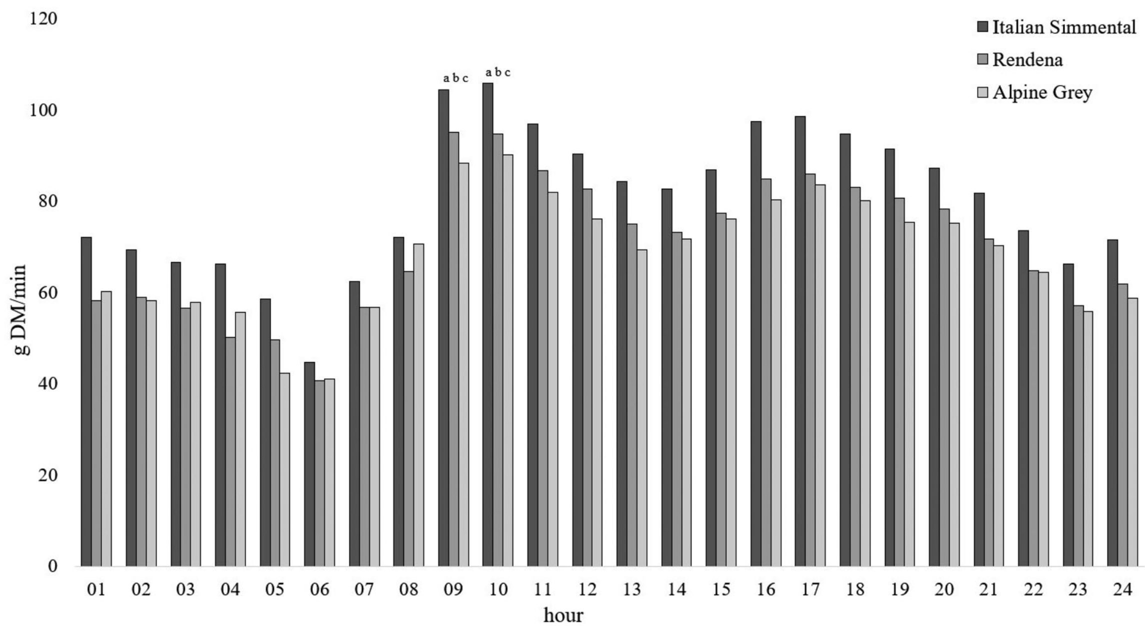


**Figure 4.** Feeding rate (g DM/min) at 1-h intervals throughout the day in RFI (residual feed intake) test (different letters over the bars within each hour of the day denote statistical differences among breeds, $p < .01$; RMSE = 48.664).

**Table 4.** Growth, feed efficiency, predicted emissions and activity time of growing bulls in RCI test.

| | Valdostana strain | | |
|---|---|---|---|
| | Red | Black | RMSE |
| *n* | 151 | 99 | – |
| BW and age | | | |
| Initial age (d) | 203.3 | 205.3 | 13.23 |
| Initial BW (kg) | 179.9 | 180.7 | 32.10 |
| Final age (d) | 263.5 | 265.7 | 13.85 |
| Final BW (kg) | 229.3 | 234.7 | 40.31 |
| Mid-test $BW^{0.75}$ (kg) | 54.0 | 54.5 | 7.05 |
| Performance | | | |
| ADG (g/d) | 816 | 887 | 215.1 |
| ADG (% BW) | $0.40^B$ | $0.43^A$ | 0.095 |
| cDMI (kg DM/d) | $4.10^B$ | $4.28^A$ | 0.300 |
| cDMI (% BW) | $2.06^B$ | $2.12^A$ | 0.187 |
| F:G (kg DM/kg) | 6.19 | 5.47 | 3.121 |
| RCI (kg DM/d) | $-0.01^B$ | $0.13^A$ | 0.302 |
| Emissions | | | |
| $CH_4$ (g/d) | $88.6^B$ | $92.4^A$ | 6.47 |
| NU (g/d) | $68.0^B$ | $70.4^A$ | 3.94 |
| NF (g/d) | $37.0^B$ | $37.9^A$ | 1.54 |
| Behaviour | | | |
| Activity (min/d) | $825.5^A$ | $766.4^B$ | 126.57 |

$^{A,B}$Means in the same row with different superscript are significantly different ($p < .01$).
ADG, average daily gain; BW, body weight; $BW^{0.75}$, metabolic body weight; cDMI, concentrate dry matter intake; $CH_4$, methane; F:G, feed to gain ratio; NF, N faecal; NU, N urinary; RCI, residual concentrate intake.

showed that AG and RE were particularly efficient breeds throughout the growth phase and had favourable RFI values. Moreover, these breeds showed low expected emissions of N and $CH_4$, which reflected differences in DMI.

Data on feeding behaviour showed how FT was not different among efficient and non-efficient breeds (Table 2) and these results were consistent with those proposed in other studies on high and low RFI bulls (Menezes et al. 2020). On the other hand, Benfica et al. (2020) argued that the FT can be a strong indicator of feed efficiency. Regarding the FEn, it was thought that a high FEn was associated with less efficient animals that had a more intense activity, as reported in a prior study (Romanzin et al. 2021) and also supported by other authors in the literature (Lancaster et al. 2009; Kelly et al. 2010).

In this study, the breed effect (e.g. AG breed) outweighs a possible influence of feed efficiency. The MEn also support this assumption. AG was a breed with restless behaviour, manifesting in a high number of FE and ME, despite being a breed with a low RFI. The FR data, on the other hand, proved to be more reliable. Bulls with a slow FR were more efficient in terms of RFI. In a review, Kenny et al. (2018) report that low-RFI growing steers, heifers, and pregnant beef females had a slower FR than their high-RFI counterparts. Even so, the correlation between FR and RFI was not particularly strong, but highly significant (Table 3).

As already reported by Azizi et al. (2009), the correlations between FEd and FEn and between DMI/FE and FEn followed a non-linear regression model. Although the breeds had significant differences in daily average data (e.g. FEn and DMI/FE; Table 2) the distribution was similar (Figure 1). In all breeds, there were many subjects with high FEn (>70) and DMI/FE around 100 g, while on the other side subjects with low FEn (<30) and DMI/FE between 300 g and 500 g.

As expected, the visual representation of differences in DMI and FT between the dual-purpose breeds showed a strong reduction during the nocturne hours, while peaks in eating activity occurred in the hours immediately next the feed delivering throughout the day (Figures 2 and 3). This was also confirmed by numerous studies (Aikman et al. 2008; Cozzi et al. 2009), where the peaks occurred after the fresh feed was placed in the feed bunk. By focussing on breeds that differed for feed efficiency, the FEn and FT did not follow RFI values, whereas DMI does. Otherwise, IS bulls ate more in a time similar to that of AG, according to the values of FR and this is probably due to the greater dimensions of the bite-size, which increased the eating speed (Beauchemin 2018). In any case, the quantity of DMI BW-related was similar to the three groups. Fitzsimons et al. (2014), in a study on pregnant beef cows divergent for RFI, found that in the first period after the ration delivery (up to 3 h later) there were no differences in DMI, whereas successively the high-RFI group had significantly higher ingestion then low-RFI group. Unlike this, we found that the less efficient breed had a higher DMI during feeding activity peaks.

As concerns FR (Figure 4), IS had the higher values during all the day, whereas RE and AG had similar behaviour. In general, feeding behaviour is known to be strongly linked to RFI, although the literature is equivocal about which behavioural traits are the most significant (Cantalapiedra-Hijar et al. 2018; Kenny et al. 2018). From our results, it would seem that even considering different behavioural traits, this effect was well distributed without particular changes over the 24 h. In a recent work (Holló et al. 2022), in which the TMR was distributed once a day, a single rather protracted dietary peak was noted. However, the differences in terms of feeding behaviour between efficient and inefficient bulls were very few. It was therefore conceivable that even if the ration distribution frequency increased there would be no change in this indicator.

In a recent study, Brown et al. (2022) investigated the relation between feeding behaviour and RFI in mid-lactation dairy cows. The interesting outcome regarding the link between FR and RFI, which was inversely proportional as is also reported in the results of our study (inefficient cows has a higher FR, and vice versa). Therefore, this behavioural trait could be an opportunity for the identification of efficient or inefficient animals. In addition, a genetic correlation between FR and RFI in steers was investigated in many studies (Chen et al. 2014; Kelly et al. 2021). The inclusion of FR in cattle selection can rely on an acceptable heritability (0.44 – 0.56) and on data generated with the use of smart technologies.

The VB strain (which includes Black Pied and Chestnut) is characterised by lower milk production and greater muscularity (Mazza et al. 2015). This was confirmed by the better growth performance compared to VR (Table 4). However, in a recent study on grazing heifers, Kreuzer et al. (2021) found no differences in growth performance between the two Valdostana strains. The higher cDMI recorded for VB determines a little bit lower efficiency in the growing phase, limited to the RCI. The difference in feed efficiency between strains was significant but numerically limited, as previously seen in Experiment 1. A study that compared four cattle breeds, both dairy and beef (Bureš and Bartoň 2018), found stronger differences in RFI, especially between Holstein (+1.55 kg DM/d) and Gascon (–1.36 kg DM/d) breeds. Valdostana strains had moderately different breeding goals, which do not much affect their feed efficiency. Surprisingly, the Chestnut strain, also selected for fighting ability (Sartori and Mantovani 2012), had a lower activity index. As previously stated for AG, even the feed efficiency of VR was not affected by its higher activity.

## Conclusions

In general, the Italian dual-purpose breeds involved in this study do not differ markedly in terms of growth rate, or feeding efficiency (measured in terms of RFI and RCI) and behaviour, and they attain relatively high levels of performance. In general, these results show that, when properly fed, dual-purpose cattle breeds—which are not under intensive breeding selection for meat production—can achieve notable growth performances with good feed efficiency levels. This result should encourage a further diffusion of these breeds.

The relationships between feeding behaviour traits and performance metrics show that FR is well related to feed efficiency (e.g. AG bulls were the most efficient with the lowest FR), while FT does not show significant differences between breeds. These findings support a research strategy that emphasises the study of mechanisms that regulate feeding behaviour traits, notably FR.

## Ethical approval

The experimental procedures followed the EU Directive 2010/63/EU, Italian legislation on animal care (DL no. 26 – 4 March 2014), and the guidelines of the Ethics Committee of

University of Udine (Prot. no. 11/2018, no. 1/2021 and no. 2/2022).

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## Data availability statement

The data that support the findings of this study are freely available upon request.

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