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Methane profiles assessment in growing Simmental bulls with divergent feed efficiency

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Abstract

There is a considerable interest in animal genetic selection to reduce the livestock sector's environmental impact, representing a permanent mitigation strategy. The methane (CH_4) total production was correlated to animal efficiency in different studies on dairy cows and steers. Several methods for CH_4 quantification have been proposed, such as the laser methane detector (LMD), a reliable, cheap and easy alternative to gold standard methods when CH_4 is assessed *in vivo*. The aim of this study was to characterize the CH_4 profile of growing Simmental bulls collected using an LMD and to relate the CH_4 production, as total or expressed in different ways, with the feed efficiency. For this purpose, 1,164 CH_4 profiles collected from 194 Italian Simmental bulls were analyzed to evaluate their main characteristics as peak type, number, and intensity. Subjects were divided into two feed efficiency groups, high ($n = 50$) and low ($n = 49$) efficiency, based on their residual feed intake (RFI), and the main traits of CH_4 production were compared. The total number of peaks observed did not differ between the two groups, with a similar average concentration (51.9 ppm-m). Likewise, the eructation peaks had shown a similar trend with no differences detected in total number and concentration. The CH_4 profile converted to g/day has shown similar values between groups. Instead, the CH_4 yield (g/kg DMI) was higher in highly efficient animals when compared to low-efficient animals (30.4 vs. 25.3 g/kg). Similarly, the residual methane emission (RME), calculated as the difference between the measured CH_4 and that estimated, was higher in the high efficiency group (74.7 vs. 35.7 g/day). Contrary to the common idea that efficient animals produce less CH_4, results indicate that total production may be similar across animals with different RFI. Instead, values could be unfavorable for highly efficient animals when CH_4 yield or RME are considered.

Lay Summary

The environmental impact of the farming sector is one of the most discussed topics, and the necessity of effective mitigation strategies increases the number of research studies in this direction. There is a considerable interest in animal genetic selection to improve animal feed efficiency, increasing the sustainability of the livestock sector and permanently mitigating emissions. Different systems to assess methane at the animal level have been proposed, each presenting different implications. Collecting reliable phenotypic data is essential to strengthening animal genetic selection. In the present study, a laser methane detector was used to collect the methane profile of growing Simmental bulls characterized by different feed efficiency. The methane profiles were analyzed to identify their main characteristics, and outcomes were compared between animals with divergent feed efficiency. Contrary to the common belief that highly efficient animals produce less methane, the results indicate that daily production is similar among animals; instead, methane production was higher in highly efficient animals when it was related to their ingestion.

Keywords enteric methane, laser methane smart, residual feed intake, residual methane emission, Simmental breed

Abbreviations: ADG, average daily gain; BW, body weight; CH4, methane; DM, dry matter; DMI, dry matter intake; eDMI, expected dry matter intake; FTIR, Fourier transform infrared; LMD, laser methane detector; LMS, laser methane smart; NDIR, non-dispersive infrared; RFI, residual feed intake; RME, residual methane emission; TMR, total mixed ration; VFA, volatile fatty acids

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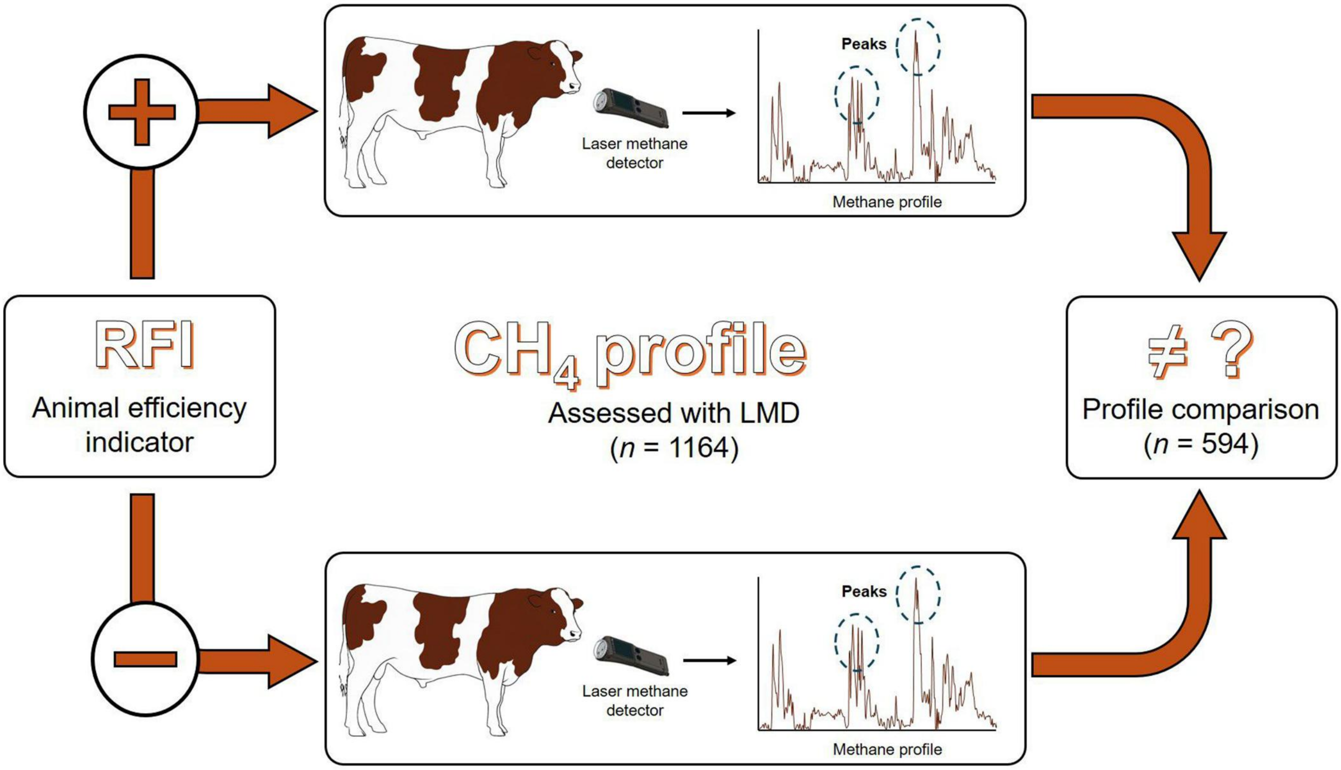
Graphical abstract



Introduction

Consulting one of the most widespread scientific databases (Scopus, keywords: methane OR methanogenesis AND rumen OR cow OR cattle OR buffaloes OR sheep OR lamb), to date, around 11,000 papers related to methane (CH_4) produced by ruminants can be found, highlighting the relevance of this research topic. Indeed, enteric CH_4 represents a significant environmental issue, accounting for 46% of the total 3.7 Gt CO_2-eq generated by the direct emissions of the livestock sector (FAO 2023).

Methanogenesis represents 2%–12% of dietary energy loss in ruminants and is reasonably related to feed efficiency. This trait has been correlated to CH_4 production in several studies on dairy cows and steers (Alemu et al. 2017; Dini et al. 2019; Manzanilla-Pech et al. 2022). Residual feed intake (RFI) is a widely used index of feed efficiency in growing animals and is calculated as the difference between actual and predicted intake (Koch et al. 1963). Animals that consume less feed than expected at equal body weight and ADG are characterized by negative RFI values. There is a considerable interest in animal genetic selection to improve animal efficiency, but also to reduce CH_4 as its production is a moderately heritable trait with an h^2 from 0.23 to 0.30 (Pickering et al. 2015; Manzanilla-Pech et al. 2016; Breider et al. 2019).

However, methanogenesis is related to other animal traits that play a central role in animal productivity (De Haas et al. 2017). For this reason, alongside the total daily CH_4 production, other ways to express CH_4 find space. The production can be reported as intensity, when it is scaled to units of animal product (g CH_4/kg milk or kg average daily gain (ADG)), or as yield when it is related to kg of feed ingested (g CH_4/kg dry matter intake (DMI)) (Crowley et al. 2024). Another indicator of the CH_4 production, and a potential selection index trait, is residual methane emission (RME) (Kim et al. 2024; Starsmore et al. 2024; Vargas et al. 2025). It is calculated as the difference between the CH_4 measured and those predicted using published equations or mathematical models and it is independent of animal feed intake (Herd et al. 2014).

Despite the different indices and modes of expression, the measure of CH_4 emission on farm conditions is a relevant issue for adopting practical strategies of mitigation. Over the years, numerous approaches based on different technologies have been proposed to detect CH_4, and each has its advantages and disadvantages, as widely reviewed (Patra 2016; Zhao et al. 2020; Tedeschi et al. 2022). Respiratory chambers, spot sampling methods (sniffers and GreenFeed), and tracer techniques (sulphur hexafluoride, SF6) represent effective and efficient solutions for monitoring animal emissions, but their application in commercial farms is limited (Chagunda et al. 2009). The portable laser methane detector (LMD) represents an alternative method applicable both at research and farm level. Originally used to detect gas leaks, the LMD has found applications in other fields, such as enteric CH_4 quantification, given its low purchase and running costs (Sorg 2021). The LMD has been compared in several studies with the above-mentioned methods as reported in Garnsworthy et al. (2019), showing good correlation and promoting this instrument as an effective solution for CH_4

measurement. Chagunda and Yan (2011) report a good correlation coefficient ($r = 0.80$) when the LMD was compared with the respiratory chamber, while the agreement tends to decrease, but remains moderately good, when it was compared to other methods adopted in a production scenario. Rey et al. (2019) reported a concordance correlation coefficient of 0.62 between CH_4 production measured using LMD and that measured simultaneously from animals' nostrils using a tube connected to an NDIR (Non-Dispersive Infrared) analyzer. Similarly, Sorg et al. (2018) observed a repeated measure correlation of 0.60 and 0.57 when comparing LMD data with those from NDIR and FTIR (Fourier Transform Infrared) installed in an automated milking system. In the same study, they have also reported a repeated measure correlation of 0.66 with the GreenFeed.

Given the growing interest in developing genetic indices for feed efficiency and CH_4 emission reduction (Richardson et al. 2025), it is essential to study these traits also outside of the experimental farms and thoroughly evaluate their potential correlations. The main aim of this study was to characterize the CH_4 profile of Simmental bulls and subsequently investigate the relationship between CH_4 production and feed efficiency.

Material and methods

Ethics statement

The experimental procedures followed EU Directive 2010/63/EU, Italian legislation on animal care (DL n. 26-4 March 2014), and the guidelines of the University of Udine. This study was approved by the Ethics Committee of the University of Udine (prot. n. 02/2024).

Animal management

The study was conducted at the Genetic Centre of Italian Simmental breed (Fiume Veneto, Friuli-Venezia Giulia, Italy) between March 2024 and March 2025. Simmental bulls were reared together under equal conditions in six-animal pens. Details on their management during their permanence in the Genetic Centre are reported in Romanzin et al. (2021). After an adaptation period of about 30 days, bulls underwent the performance test until they were 12 months old. All animals were fed *ad libitum* with the same diet distributed daily and consisting of a total mixed ration (TMR) composed of ground corn (28.2% DM), corn silage (27.2% DM), sunflower and rapeseed meals (14.6% DM), wheat straw (8.7% DM), barley meal (5.9% DM), dried beet pulp (5.8% DM), wheat bran (5.8% DM), soybean meal (1.9% DM) and a mix of vitamins and minerals (1.9% DM). The TMR had an average content of 59.8% of DM, 39.9% DM of neutral detergent fibre, 13.6% DM of crude protein, and 6.8% DM of ash.

During the performance test the animals were weighed every 42 days, and bulls were subjected to the RFI trial, which lasted around 2 months. Subjects, approximately 9 months old, were moved to pens equipped with two electronic feeders each (RIC system; Hokofarm Group, Marknesse, The Netherlands), which allowed for animals' identification and the individual assessment of daily feed intake.

Methane assessment

To monitor the CH_4 production of Simmental bulls, 208 subjects were monitored in 12 consecutive months using a Laser Methane Smart (LMS; Tokyo Gas Engineering Solution Corporation, Tokyo, Japan), an updated version of LMD, adapting the protocols suggested by (ICAR 2020) and other relevant papers that used the LMD (Chagunda et al. 2009; Ricci et al. 2014; Pickering et al. 2015; Sorg et al. 2018). Six measurements (2 measurements per day × 3 sampling days) lasting 5 min each were taken from each bull, resulting in 1,248 CH_4 profiles collected. All measurements were performed with animals in the feed bunk. The first was collected immediately after feed distribution (approximately 8:00 AM), and the second was performed in the afternoon (approximately 3:00 PM) after pushing the remaining TMR close to the animals. A trained operator directed the visible laser, a directional reference present in the instrument, towards the bull's nostrils, maintaining an average distance of 1 m and following the head movement. The CH_4 concentration in the air column between LMD and the animal was detected every 0.5 s and expressed as ppm-m. The raw data was downloaded directly from the internal storage card.

Data management and statistical analysis

The RFI was computed for each animal and represents the residual from the following multiple linear regression used to estimate the expected DMI (eDMI):

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

where BW is the mid-test BW; ADG is the average daily gain; α, β, and γ are parameters of the regression equation; ε is the error term. Bulls with missing data were excluded from the analysis, leading to a final dataset with 194 subjects.

Peaks in the CH_4 profile were identified using the function *findpeaks* available in the Pracma package v. 2.4.4 (Borchers 2023) of R software v. 4.4.3 (R Core Team 2021). The main characteristics of the CH_4 profile and the conversion to g/day were performed following Sorg et al. (2018). To identify and remove outliers, CH_4 was predicted using a regression approach considering the day and month of sampling, and the residuals were divided by the standard deviation of the original data, as proposed by Coppa et al. (2021). If the ratio was higher than 3, the observation was removed. In total, 1.6% of the total observations were deleted, and the final dataset included 1,146 CH_4 profiles.

The RME for each animal was calculated as the difference between the measured CH_4 and that estimated using the following equation adapted from IPCC (2006):

$$Estimate\ CH_4 = \frac{DMI \times 18.45 \times (6.5 \times 10)}{55.65}$$

where 18.45 is the average dietary gross energy content (MJ/kg DM), 6.5 is the extent of gross energy converted to CH_4 (%), and 55.65 is the energetic content of CH_4 (MJ/kgCH_4). The gross energy value of the diet was calculated adopting tabulated values, according to the French evaluating system (INRA 2018). The distribution of animals' RFI was evaluated with the UNIVARIATE procedure of SAS software (version 9.4; SAS Institute), taking into account the first and the third quartile. Subjects were divided into two feed efficiency groups (high and low, $n = 50$ and $n = 49$, respectively). Data concerning animals' characteristics were statistically analyzed using the GLM procedure following a factorial model considering the RFI as a fixed factor. The CH_4 profile characteristics (total CH_4, CH_4 yield, CH_4 intensity, and RME) were analyzed using the MIXED procedure of SAS, with parameters estimated by restricted maximum likelihood (REML). The model accounted for the repeated-measures experimental design and included month of sampling (1–13) and efficiency group (1–2) as fixed effects, with a random intercept for subject (1–99). Within-subject correlation among repeated measurements was modelled using a first-order autoregressive AR(1) covariance structure. Least-squares means and their 95% confidence intervals, were estimated for the efficiency group using LSMEANS option. The effects were considered statistically significant at $P < 0.05$. Lastly, the CH_4 yield was deeply analyzed considering all the animals' records (1–194) using the same model previously described but considering the RFI as continuous predictor including it as fixed covariate instead of fixed class effect.

Results

Animals' characteristics

The 194 Simmental bulls taken into account in the current trial had an average BW of 437 kg and were characterized by an average DMI of 9.74 kg/day and an ADG of 1.64 kg/day. The average production of CH_4 measured with LMS was around 267 g/day.

The main characteristics of animals in the two efficiency groups are reported in Table 1. Their RFI values differ significantly ($P < 0.001$), with an average value of −0.94 kg/day for the high efficiency group and a value of 0.59 kg/day for the low efficiency one, with an absolute difference of 1.53 kg/day. As reported, the bulls in the two groups did not differ in BW and ADG with an average value of 436 kg and 1.66 kg/day. However, the two groups differed significantly in their DMI ($P < 0.001$), with higher intake for the low efficiency group when compared to the high efficiency one (10.6 vs. 8.81 kg/day, respectively).

Methane traits

Figure 1 shows an example of a CH_4 profile collected and highlights its main characteristics. For each animal, the CH_4 profiles collected were analyzed, and the results are presented in Table 2. The total number of peaks observed did not differ between the two groups, with an average value of around 125 peaks. Furthermore, their concentration was quite similar, with an average value of 51.9 ppm-m, and no significant variations were observed. Likewise, the eructation peaks had shown a similar trend, with no differences detected between high and low efficiency groups in their total number (21.1 vs. 21.7, for high and low efficiency, respectively) or concentration (165 vs. 162 ppm-m, for high and low efficiency, respectively).

Table 1 Main characteristics of animal considered in the two feed efficiency groups. Data were reported as estimate mean ± standard error (95% confidence interval).

	Efficiency		RMSE	*P*-Value
	High	Low		
RFI, kg/day	−0.94 ± 0.05 (−1.04 to −0.83)	0.59 ± 0.04 (0.52 to 0.71)	0.326	<0.001
BW, kg	430 ± 8.11 (418 to 450)	442 ± 8.04 (421 to 453)	52.6	0.792
ADG, kg/day	1.63 ± 0.03 (1.55 to 1.68)	1.69 ± 0.03 (1.63 to 1.76)	0.219	0.114
DMI, kg/day	8.81 ± 0.12 (8.60 to 8.85)	10.6 ± 0.12 (10.3 to 10.5)	0.811	<0.001

RFI: residual feed intake; BW: body weight; DMI: dry matter intake; ADG: average daily gain; RMSE: root mean square error.

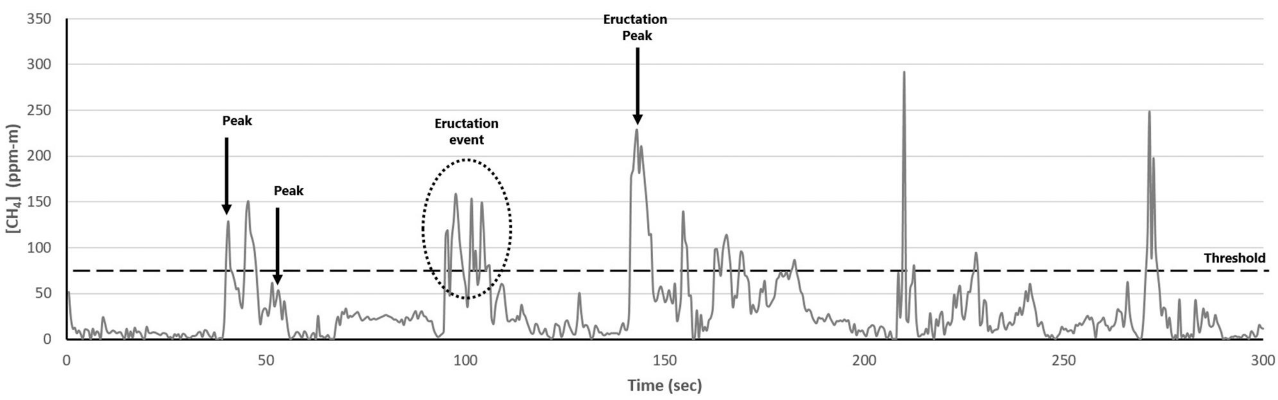


Figure 1 Example of methane profile collected with laser methane detector. The threshold used for the differentiation between normal and eructation peaks was calculated from raw data taking into account the interquartile range as reported in Sorg et al. (2018).

Table 2 Main parameters of methane profile identified for high and low feed efficiency. Data were reported as estimate mean ± standard error (95% confidence interval).

	Efficiency		*P*-Value
	High	Low	
Total peaks, *n*	126 ± 0.85 (124 to 128)	125 ± 0.83 (124 to 127)	0.826
Peaks concentration, ppm-m	52.5 ± 2.09 (48.4 to 56.6)	51.4 ± 2.05 (47.5 to 55.6)	0.723
Eructation peaks, *n*	21.1 ± 0.501 (20.1 to 22.1)	21.7 ± 0.49 (20.8 to 22.7)	0.320
Eructation peaks concentration, ppm-m	165 ± 7.01 (152 to 179)	162 ± 6.90 (148 to 175)	0.667

Table 3 Methane as total production, intensity (methane/ADG), yield (methane/DMI), and RME (measured-estimated) for the two efficiency groups. Data were reported as estimate mean ± standard error (95% confidence interval).

	Efficiency		*P*-Value
	High	Low	
Methane, g/day	265 ± 4.59 (256 to 274)	263 ± 4.52 (254 to 272)	0.723
Methane/ADG, g/kg	170 ± 5.25 (159 to 180)	161 ± 5.19 (146 to 166)	0.072
Methane/DMI, g/kg	30.4 ± 0.60 (29.2 to 31.6)	25.3 ± 0.59 (23.7 to 26.1)	$<$0.001
RME, g/day	74.7 ± 5.04 (64.8 to 84.6)	35.7 ± 4.97 (25.9 to 45.5)	$<$0.001

ADG: average daily gain; DMI: dry matter intake; RME: residual methane emission.

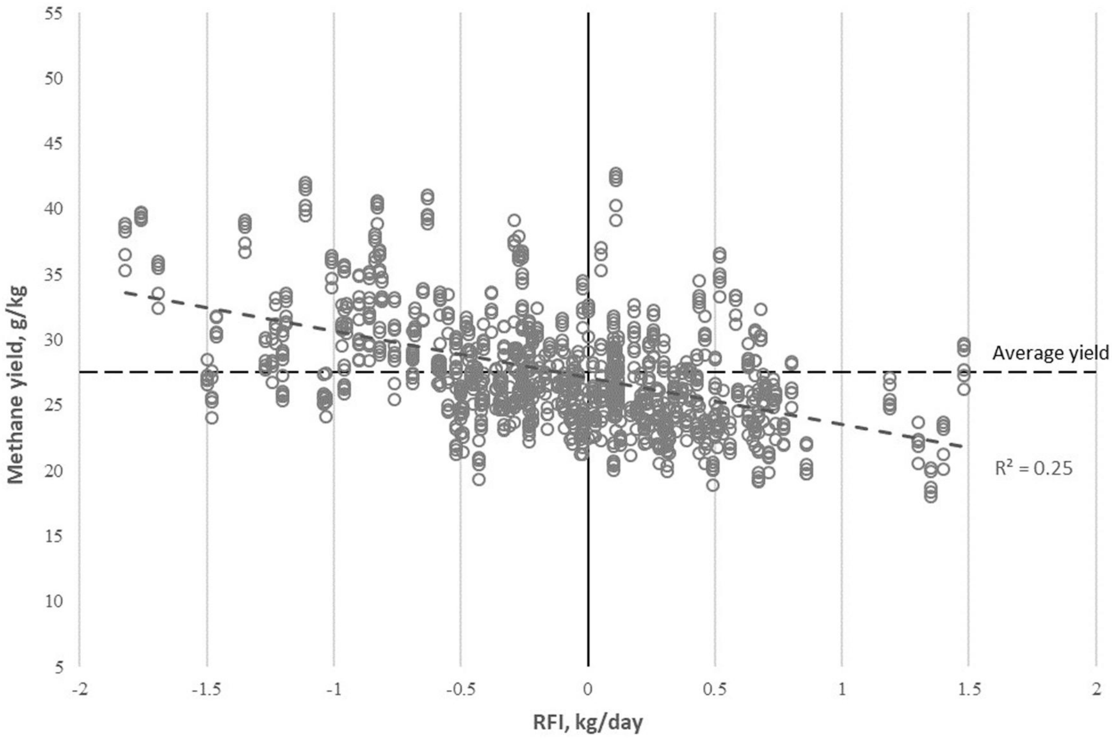


Figure 2 Effect of residual feed intake (RFI) on the methane yield (methane/DMI) of animals used in the present study ($n = 194$).

Table 3 reports the CH_4 produced expressed in different ways. Daily production, expressed in g/day, was similar between the groups, with no significant variations registered (265 vs. 263 g/day for high and low efficiency, respectively). When CH_4 was expressed as intensity (g/kg ADG), a tendency toward a lower value was observed in the low efficiency group ($P = 0.072$), with a value of 161 g/kg compared to 170 g/kg reached by the high efficiency one. Considering CH_4 yield (g/kg DMI), a significant difference was observed ($P < 0.001$) with the high efficiency bulls showing a higher value (30.4 g/kg) than the low efficiency ones

(25.3 g/kg). Finally, the resulting RME varied between groups, with a significantly higher value ($P < 0.001$) for the high efficiency group (74.7 g/day) compared to the low efficiency one (35.7 g/day).

Lastly, Figure 2 evaluates the effect of RFI on CH_4 yield across all bulls considered in the present study ($n = 194$). A significant effect of feed efficiency ($P < 0.001$) was found, with an overall decrease in CH_4 yield as the RFI increased ($R^2 = 0.25$).

Discussion

Animal performance and methane measures

The Italian Simmental growing bulls involved in the present trial were subjected to a performance test under feeding and rearing conditions similar to those used in fattening farms. Their main traits, such as DMI and ADG, are comparable to those of animals of the same breed used in previous studies conducted at the same centre (Spanghero et al. 2017; Cesarani et al. 2020; Romanzin et al. 2022). All animals had similar BW and ADG, but the RFI values diverged, resulting in a significant difference in DMI between the two groups. As expected, bulls with a negative RFI needed less feed to maintain a comparable level of growing performance (Herd et al. 2003). The average DMI difference registered between the two feed efficiency groups was similar to that reported by Romanzin et al. (2024), with the high efficiency group consuming around 16% less feed than the low efficiency group.

Considering the CH_4 profile, LMD is currently widely utilized to analyze the CH_4 emission in different species such as dairy cows, sheep, beef cattle, buffaloes, and goats (Sorg 2021). However, not all of these studies differentiate profile peaks. Ricci et al. (2014) considered the CH_4 emission of beef steers fed with two different diets using LMD. The values reported for the average peak concentration (average 53.35 ppm-m) are comparable to those achieved in the current study, while the average eructation peaks (average 93.9 ppm-m) result slightly lower. In contrast, in a recent work on Simmental bulls, Koch et al. (2025) have reported an average peak concentration greater than our outcomes, but no further information inherent to the CH_4 profile was described.

Overall, in our experimental conditions, the profile characteristics did not differ significantly between the two groups considered. In other scientific works, authors have found a variation in CH_4 profile characteristics, but in these cases, the main factor considered was the diet fed to the animals. Kang et al. (2022) found a variation in peak concentration and in eructation peak concentration in an experiment conducted on 30 animals fed with two diets with different in their forage to concentrate ratio. Similarly, Ricci et al. (2014) highlighted differences in the CH_4 profile of 72 animals fed with high and low concentrate diets, with alteration in peaks and eructation peaks concentration. Based on the literature, a differentiation in animals' CH_4 profile characteristics can occur mainly related to peaks concentration. We can hypothesize that RFI alone is not sufficient to generate such differentiation while other factors, as diet composition, can alter significantly the CH_4 production pattern registered with LMD.

Relationship between residual feed intake and methane traits

In contrast to the hypothesis that CH_4 is related to animal efficiency, the two groups did not differ in their daily production (g/day). This finding is analogous to those of other authors (McDonnell et al. 2016; Flay et al. 2019; Renand et al. 2019), highlighting the absence of a strong correlation between animal efficiency and CH_4 production. However, the lack of a significant difference between the groups, could be explained by considering the animals' DMI.

In fact, interesting results were observed in CH_4 yield (g/kg DMI) with a significantly higher value detected for the highly efficient bulls. Overall, the values of CH_4 yield assessed in the present trial are similar to those reported in previous studies on animals with comparable BW and ADG (Alemu et al. 2017; Batalha et al. 2020). Moreover, a similar difference between efficiency groups was achieved in a previous work published by Flay et al. (2019). The researchers have evaluated the relationship between CH_4, collected using the GreenFeed system, and the RFI of 56 dairy heifers, highlighting a significant difference in CH_4 yield, with the highest value recorded for the group of efficient animals. Similarly, Smith et al. (2021), in an experiment conducted on 294 crossbreed beef cattle, gathered emission data with the GreenFeed system and detailed a significant negative correlation between RFI and CH_4 yield. This outcome was observed once again in a recent meta-analysis of 27 studies conducted by Soares et al. (2025). The work had analyzed the relationship between different CH_4 emission traits and RFI, finding a large heterogeneity across studies, but overall, 75% of the considered studies report a negative correlation between RFI and CH_4 per unit of DMI. The same trend was observed in the present study (Figure 2), with a decrease in CH_4 yield as RFI increased ($R^2 = 0.25$, $P < 0.001$).

This outcome suggests an interaction between DMI, rumen fermentation, and CH_4 production.

In a review on the biological determinants of feed efficiency, Cantalapiedra-Hijar et al. (2018) identified an overall negative correlation between DMI and DM digestibility in animals with opposite RFI. It is known that a high DMI, typical of animals with a high RFI index (low efficiency), significantly increases the feed passage rate, with a consequent negative effect on ruminal organic matter fermentation (Kenny et al. 2018). Besides the alteration in DM digestibility, rumen passage rate influences the proportions of volatile fatty acids (VFA) produced and the ruminal microbiota (Knapp et al. 2014), all aspects related to methanogenesis, as reported in several scientific works (Wang et al. 2009; Spanghero et al. 2022; Zhang et al. 2023). The comparable daily CH_4 production observed in the present trial, and obtained by other authors as mentioned above, can be attributed to more intense ruminal fermentation in efficient animals that leads to a more intense production of CH_4 per unit of DMI. However, it should be noted that literature reports a strong positive relationship between animal CH_4 output and DMI (De Haas et al. 2011; Fitzsimons et al. 2013; McDonnell et al. 2016; Bird-Gardiner et al. 2017), promoting this aspect as a main driver in apparent contrast with the previously discussed results. Generally, the correlation reported in scientific works derives from trials where the genetic variability in terms of animals' feed efficiency is not considered and is randomly distributed among factors taken into account. On the contrary, when animals are intentionally compared based on their feed efficiency, variations in CH_4 production arise from a combination of their feeding behavior and digestive physiology.

This hypothesis is strengthened by the results reached with RME, a trait that results independently from DMI and animal production but is positively correlated to the CH_4 emissions (Bird-Gardiner et al. 2017; Renand et al. 2019). This characteristic promotes it as a useful indicator for animal selection as a possible solution to reduce the livestock impact (Herd et al. 2014). As observed in the current study, Sakamoto et al. (2021) achieved a higher value in RME in Nellore cattle characterized by negative RFI. Smith et al. (2021) studied the CH_4 emissions in finishing beef cattle and reported that animals characterized with low RME value have also low CH_4 yields, in agreement with the results presented in this study. Silva et al. (2025) analyzed records in several years from over 2,000 animals, stating a strong positive genetic correlation between the RME and CH_4 yield, with a consequent higher value of RME in animals that produce more CH_4 per unit of DMI. These outcomes support the hypothesis that animals with different feed efficiency have a different utilization of feed ingested, resulting in a measured CH_4 value greater than theoretical and therefore defined by high RME. All these results suggested that improving efficiency does not necessarily mean a reduction in animal impact, and further aspects have to be considered.

Conclusion

Various factors influence enteric CH_4 emission, but residual feed intake appears uncorrelated to the main traits that define the CH_4 profile. Furthermore, contrary to the common idea that efficient animals produce less CH_4, results indicate that total production might be similar across animals with differing RFI. Instead, differences could be unfavorable for highly efficient animals when CH_4 yield or RME are considered. There is no doubt that selecting for feed efficiency provides lasting economic and environmental benefits. However, feed efficiency alone is likely not sufficient to reduce enteric CH_4 emissions, and further efforts are needed to identify an effective strategy.

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Author contributions

Matteo Braidot (Data curation, Formal analysis, Investigation, Methodology, Writing—original draft), Anita Cabbia (Formal analysis, Writing—review & editing), Mauro Spanghero (Resources, Writing—review & editing), Damiano Cavallini (Funding acquisition, Writing—review & editing), and Alberto Romanzin (Conceptualization, Funding acquisition, Investigation, Methodology, Writing—original draft)

Conflict of interest statement. Authors declare no conflict of interest.

Data availability statement

The data underlying this article will be shared on reasonable request to the corresponding author.

References

Alemu AW, Vyas D, Manafiazar G, Basarab JA, Beauchemin KA. 2017. Enteric methane emissions from low– and high–residual feed intake beef heifers measured using GreenFeed and respiration chamber techniques. J Anim Sci. 95:3727–3737. https://doi.org/10.2527/jas.2017.1501

Batalha CDA et al. 2020. Association between residual feed intake, digestion, ingestive behavior, enteric methane emission and nitrogen metabolism in Nellore beef cattle. Anim Sci J. 91:e13455. https://doi.org/10.1111/asj.13455

Bird-Gardiner T, Arthur PF, Barchia IM, Donoghue KA, Herd RM. 2017. Phenotypic relationships among methane production traits assessed under ad libitum feeding of beef cattle. J Anim Sci. 95:4391–4398. https://doi.org/10.2527/JAS2017.1477

Breider IS, Wall E, Garnsworthy PC. 2019. Heritability of methane production and genetic correlations with milk yield and body weight in Holstein-Friesian dairy cows. J Dairy Sci. 102: 7277–7281. https://doi.org/10.3168/jds.2018-15909

Borchers H. 2023. pracma: Practical Numerical Math Functions. R package version 2.4.4, https://CRAN.R-project.org/package=pracma.

Cantalapiedra-Hijar G et al. 2018. Review: biological determinants of between-animal variation in feed efficiency of growing beef cattle. Animal. 12:s321–s335. https://doi.org/10.1017/s1751731118001489

Cesarani A. 2020. Beef trait genetic parameters based on old and recent data and its implications for genomic predictions in Italian Simmental cattle. J Anim Sci. 98:1–8. https://doi.org/10.1093/jas/skaa242

Chagunda MGG, Ross D, Roberts D. 2009. On the use of a laser methane detector in dairy cows. Comput Electron Agric. 68: 157–160. https://doi.org/10.1016/j.compag.2009.05.008

Chagunda MGG, Yan T. 2011. Do methane measurements from a laser detector and an indirect open-circuit respiration calorimetric chamber agree sufficiently closely? Anim Feed Sci Technol. 165:8–14. https://doi.org/10.1016/j.anifeedsci.2011.02.005

Coppa M et al. 2021. Repeatability and ranking of long-term enteric methane emissions measurement on dairy cows across diets and time using GreenFeed system in farm-conditions. Methods. 186:59–67. https://doi.org/10.1016/j.ymeth.2020.11.004

Crowley SB et al. 2024. Associations between a range of enteric methane emission traits and performance traits in indoor-fed growing cattle. J Anim Sci. 102:skae346. https://doi.org/10.1093/jas/skae346
Haas D et al. 2011. Genetic parameters for predicted methane production and potential for reducing enteric emissions through genomic selection. J Dairy Sci. 94:6122–6134. https://doi.org/10.3168/jds.2011-4439
De Haas Y, Pszczola M, Soyeurt H, Wall E, Lassen J. 2017. Invited review: Phenotypes to genetically reduce greenhouse gas emissions in dairying. J Dairy Sci. 100:855–870. https://doi.org/10.3168/jds.2016-11246
Dini Y et al. 2019. Association between residual feed intake and enteric methane emissions in Hereford steers. Transl Anim Sci. 3:239–246. https://doi.org/10.1093/tas/txy111
FAO. 2023. Pathways towards lower emissions – a global assessment of the greenhouse gas emissions and mitigation options from livestock agrifood systems. Rome, Italy. https://doi.org/10.4060/cc9029en
Flay H et al. 2019. Hot topic: selecting cattle for low residual feed intake did not affect daily methane production but increased methane yield. J Dairy Sci. 102:2708–2713. an https://doi.org/10.3168/jds.2018-15234
Fitzsimons C, Kenny DA, Deighton MH, Fahey AG, McGee M. 2013. Methane emissions, body composition, and rumen fermentation traits of beef heifers differing in residual feed intake. J Anim Sci. 91:5789–5800. https://doi.org/10.2527/jas.2013-6956
Garnsworthy PC et al. 2019. Comparison of methods to measure methane for use in genetic evaluation of dairy cattle. Animals (Basel). 9:837. https://doi.org/10.3390/ani9100837
Herd RM, Archer JA, Arthur PF. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: opportunity and challenges to application. J Anim Sci. 81:E9–E17. https://doi.org/10.2527/2003.8113_suppl_1e9x
Herd RM et al. 2014. Measures of methane production and their phenotypic relationships with dry matter intake, growth, and body composition traits in beef cattle. J Anim Sci. 92:5267–5274. https://doi.org/10.2527/jas.2014-8273
ICAR. 2020. Section 20 – Methane Emission for Genetic Evaluation. Retrieved August 28, 2025 from https://www.icar.org/Guidelines/20-Recording-Dairy-Cattle-Methane-Emission-for-.Genetic-Evaluation.pdf
INRA. 2018. Alimentation des ruminants. 4th ed. Editions Quae. Versailles, France.
IPCC. 2006. Guidelines for national greenhouse gas inventories. In: Eggelston HS, Buendia L, Miwa K, Ngara T, Tanabe K. Vol. 4, Agriculture, forestry and other land use. Institute for Global Environmental Strategies, Japan.
Kang K et al. 2022. Application of a hand-held laser methane detector for measuring enteric methane emissions from cattle in intensive farming. J Anim Sci. 100:1–12. https://doi.org/10.1093/jas/skac211
Kenny DA, Fitzsimons C, Waters SM, McGee M. 2018. Invited review: improving feed efficiency of beef cattle–the current state of the art and future challenges. Animal. 12:1815–1826. https://doi.org/10.1017/s1751731118000976
Kim M et al. 2024. Effect of residual methane emission on physiological characteristics and carcass performance in Japanese Black cattle. Anim Sci J. 95:e13954. https://doi.org/10.1111/asj.13954
Knapp J, Laur G, Vadas P, Weiss W, Tricarico J. 2014. Invited review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions. J Dairy Sci. 97:3231–3261. https://doi.org/10.3168/jds.2013-7234
Koch RM, Swiger LA, Chambers DT, Gregory KE. 1963. Efficiency of feed use in beef cattle. J Anim Sci. 22:486–494. https://doi.org/10.2527/jas1963.222486x
Koch C et al. 2025. Growth performance, enteric methane emissions, and economic impact of alternative feeding strategies for Simmental fattening bulls. Trans Anim Sci. 9:txaf043. https://doi.org/10.1093/tas/txaf043
Manzanilla-Pech CIV et al. 2016. Genomewide association study of methane emissions in Angus beef cattle with validation in dairy cattle. J Anim Sci. 94:4151–4166. https://doi.org/10.2527/jas.2016-0431
Manzanilla-Pech CIV, Stephansen RB, Difford GF, Løvendahl P, Lassen J. 2022. Selecting for feed efficient cows will help to reduce methane gas emissions. Front Genet. 13:885932. https://doi.org/10.3389/fgene.2022.885932
McDonnell RP et al. 2016. Effect of divergence in phenotypic residual feed intake on methane emissions, ruminal fermentation, and apparent whole-tract digestibility of beef heifers across three contrasting diets. J Anim Sci. 94:1179–1193. https://doi.org/10.2527/jas.2015-0080
Patra AK. 2016. Recent advances in measurement and dietary mitigation of enteric methane emissions in ruminants. Front Vet Sci. 3:39. https://doi.org/10.3389/fvets.2016.00039
Pickering NK et al. 2015. Genetic parameters for predicted methane production and laser methane detector measurements. J Anim Sci. 93:11–20. https://doi.org/10.2527/jas.2014-8302
R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.
Rey J et al. 2019. Comparison between non-invasive methane measurement techniques in cattle. Animals (Basel). 9:563. https://doi.org/10.3390/ani9080563
Renand G, Vinet A, Decruyenaere V, Maupetit D, Dozias D. 2019. Methane and carbon dioxide emission of beef heifers in relation with growth and feed efficiency. Animals (Basel). 9:1136. https://doi.org/10.3390/ani9121136
Ricci P et al. 2014. Evaluation of the laser methane detector to estimate methane emissions from ewes and steers. J Anim Sci. 92:5239–5250. https://doi.org/10.2527/jas.2014-7676
Richardson C et al. 2025. Review: Breeding for sustainability: development of an index to reduce greenhouse gas in dairy cattle. Animal. 19 Suppl 2:101491. https://doi.org/10.1016/j.animal.2025.101491
Romanzin A, Degano L, Vicario D, Spanghero M. 2021. Feeding efficiency and behavior of young Simmental bulls selected for high growth capacity: comparison of bulls with high vs. low residual feed intake. Livest Sci. 249:104525. https://doi.org/10.1016/j.livsci.2021.104525
Romanzin A, Florit E, Degano L, Spanghero M. 2022. Feeding efficiency and behaviour of growing bulls from the main Italian dual-purpose breeds. Ital J Anim Sci. 21:1611–1621. https://doi.org/10.1080/1828051x.2022.2146006

Romanzin A, Braidot M, Beraldo P, Spanghero M. 2024. Rumen fermentation parameters and papillae development in Simmental growing bulls with divergent residual feed intake. Animal. 18:101149. https://doi.org/10.1016/j.animal.2024.101149

Sakamoto LS et al. 2021. Phenotypic association among performance, feed efficiency and methane emission traits in Nellore cattle. PLoS One. 16:e0257964. https://doi.org/10.1371/journal.pone.0257964

SAS Institute, Statistical Analysis Software 9.4.SAS Institute Inc. North Carolina, USA. 2013. https://www.sas.com/

Silva JA et al. 2025. Genetic parameters of methane emission, feed efficiency, feeding behaviour, and growth traits in beef cattle. J Anim Breed Genet. 1–12. https://doi.org/10.1111/jbg.70037

Smith PE et al. 2021. Effect of divergence in residual methane emissions on feed intake and efficiency, growth and carcass performance, and indices of rumen fermentation and methane emissions in finishing beef cattle. J Anim Sci. 99:1–13. https://doi.org/10.1093/jas/skab275

Soares TLS et al. 2025. A systematic review and meta-analysis: relationship between residual feed intake and traits related to methane emissions in cattle. Trop Anim Health Prod. 57:171–187. https://doi.org/10.1007/s11250-025-04423-6

Sorg D et al. 2018. Comparison of a laser methane detector with the GreenFeed and two breath analysers for on-farm measurements of methane emissions from dairy cows. Comput Electron Agric. 153:285–294. https://doi.org/10.1016/j.compag.2018.08.024

Sorg D. 2021. Measuring livestock CH4 emissions with the laser methane detector: a review. Methane. 1:38–57. https://doi.org/10.3390/methane1010004

Spanghero M, Mason F, Zanfi C, Nikulina A. 2017. Effect of diets differing in protein concentration (low vs medium) and nitrogen source (urea vs soybean meal) on in vitro rumen fermentation and on performance of finishing Italian Simmental bulls. Livest Sci. 196:14–21. https://doi.org/10.1016/j.livsci.2016.12.004

Spanghero M, Braidot M, Fabro C, Romanzin A. 2022. A meta-analysis on the relationship between rumen fermentation parameters and protozoa counts in in vitro batch experiments. Anim Feed Sci Technol. 293:115471. https://doi.org/10.1016/j.anifeedsci.2022.115471

Starsmore K et al. 2024. Residual methane emissions in grazing lactating dairy cows. N Z J Agric Res. 67:285–295. https://doi.org/10.1080/00288233.2023.2277239

Tedeschi LO et al. 2022. Quantification of methane emitted by ruminants: a review of methods. J Anim Sci. 100: 1–22. https://doi.org/10.1093/jas/skac197

Vargas J, Manriquez D, Swenson M, Carvalho PHV, Place SE. 2025. Enteric methane emission classification and ranking of growing steers during the backgrounding and finishing phases. J Anim Sci. 103:skaf046. https://doi.org/10.1093/jas/skaf046

Wang Y, Zhang Y, Wang J, Meng L. 2009. Effects of volatile fatty acid concentrations on methane yield and methanogenic bacteria. Biomass Bioenergy. 33:848–853. https://doi.org/10.1016/j.biombioe.2009.01.007

Zhang B et al. 2023. Methane prediction equations including genera of rumen bacteria as predictor variables improve prediction accuracy. Sci Rep. 13:21305., https://doi.org/10.1038/s41598-023-48449-y

Zhao Y et al. 2020. A review of enteric methane emission measurement techniques in ruminants. Animals (Basel). 10:1004. https://doi.org/10.3390/ani10061004

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https://doi.org/10.1093/jas/skag076
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