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Greenhouse gas emissions, dry matter intake and feed efficiency of young Holstein bulls

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ABSTRACT

Livestock farming is directly responsible for greenhouse gas (GHG) emissions, mainly due to enteric fermentation. Feed efficiency in livestock species is generally evaluated through feed conversion ratio (FCR) and residual feed intake (RFI), which are associated to GHG emissions. The aim of this study was to characterise FCR and RFI in relation to body traits, feed intake, feeding behaviour and GHG emissions of Holstein bulls. Data were collected between May 2018 and July 2020 on 111 animals. Pearson correlations between studied traits were estimated on the residuals obtained from a linear mixed model which included the fixed effect of the linear covariate of age of bull on the dependent variable and the random effect of the bull. To assess the effect of RFI and FCR the same linear mixed model was implemented firstly by including the fixed effect of RFI (2 classes) and secondly the fixed effect of FCR (2 classes). Correlations between dry matter intake (DMI) and GHG ranged from 0.25 (CH_4) to 0.36 (CO_2). The strongest relationship was estimated between feed efficiency traits and DMI (0.86). RFI and FCR showed weak to moderate correlations with GHG (0.12–0.31). Animals belonging to the low classes of RFI and FCR had lower DMI and showed significant reduction of GHG emissions. Results of the present study highlighted significant differences in terms of feed efficiency and GHG emissions among tested animals; further research is needed on their progeny to investigate the genetic background of the same efficiency and emission-related traits.

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KEYWORDS
Greenhouse gas; young bull; feed efficiency; genetic; environment

HIGHLIGHTS

- Feed efficiency and emission of greenhouse gases vary among Holstein bulls.
- Dry matter intake and feed efficiency traits were strongly positively associated.
- Animals endowed with greater feed efficiency had lower emissions and feed intake.
- Results of the present study will be useful to select animals for feed efficiency.

Introduction

Global average temperature has increased by about 0.7 °C in the last century. The Intergovernmental Panel on Climate Change reported that anthropogenic greenhouse gases (GHG), including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons, have been responsible for most of the observed temperature increase since the middle of the twentieth century. In particular, these gases enhance the effects of solar and thermal radiation on earth surface, which in turn increase the atmospheric temperature (Knapp et al. 2014). Greenhouse gases are often expressed on a CO_2-equivalent basis to harmonise the contribution of CO_2, CH_4 and N_2O on the global warming.

Agriculture and livestock sectors are recognised as important contributors to global temperature increase (Cassandro et al. 2013). Livestock farming, with particular regard to ruminants, is indirectly linked to GHG emissions due to enteric fermentation. Furthermore, livestock sector indirectly contributes to GHG emissions through activities related to feed production, manure spreading and storage, nitrogenous fertilisers, fossil fuels consumption and deforestation. Styles et al. (2018) demonstrated that an intensification of dairy production system can lead to the increase of GHG

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emissions through landscape and land use change, due to a reduction of natural habitats, which are considered as carbon store sites. Approximately 37% of global agricultural CH_4 and N_2O arise from animals and manure emissions (EPA Environmental Protection Agency 2011). Methane is the major GHG produced by ruminants, with CH_4 from enteric fermentation accounting for 11%–17% of CH_4 globally emitted (natural and anthropic sources) and for 17%–30% of CH_4 from human activities (anthropic sources) (Beauchemin et al. 2009), which is almost 3% of all anthropogenic emissions (Gerber et al. 2013). Methane is strongly associated with global warming, therefore its mitigation, especially in ruminants, has become one of the most important research areas (De Haas et al. 2011).

In this scenario, global protein consumption from dairy products increased from 7 g $capita^{-1} day^{-1}$ in 2001 to 8 g $capita^{-1} day^{-1}$ in 2011 and it is expected to increase further in the next years (FAO 2015). The future of livestock farming will be driven by the increase of global population and demand of animal and livestock products, which are known for their nutritional value and social sustainability. Expected population growth will likely increase food consumption, with meat and milk intake doubling by 2050 compared to 2000 (FAO 2006). In this perspective, the Food and Agriculture Organisation declared that within 2050, farmers will be asked to produce more food in environmentally sustainable way.

Recently, the scientific community has focussed on different strategies and approaches to reduce ruminants' emissions. These strategies succeeded at least partially in reducing environmental impact and simultaneously increasing production efficiency (Niero et al. 2020). Ultimate tools provided by genetic selection and improved feed efficiency can decrease CH_4 emitted per unit of product (meat or milk; Knapp et al. 2014). Previous studies reported that CH_4 emissions account for 2–12% of the gross energy consumed by ruminants (Johnson and Johnson 1995; Beauchemin et al. 2020). For this reason, improving feed efficiency of dairy cattle would result in enhanced farm profitability and reduced environmental footprint of the dairy sector (Li et al. 2019). In this context, diet formulation plays a central role in CH_4 production; indeed, it is well known that compared to forage-based diets, concentrate based diets are associated with lower CH_4 losses (Johnson and Johnson 1995) because fermentation of starch results in more propionate and less butyrate than cellulose, contributing to the mitigation of methanogenesis (Wang et al. 2014). High starch diets also contribute to the reduction of ruminal pH, which in turn inhibits the growth of methanogenic microbes (Beauchemin et al. 2020). As reported by Grandl et al. (2019) also the longevity of dairy cows is gaining interest as a potential strategy of GHG mitigation. Moreover, Garnsworthy (2004) reported that the improvement of cattle fertility is associated to a reduction of CH_4 emissions, because fertility influences the replacement rate of the herd. One of the most effective strategy to reduce CH_4 emissions consists in the application of genetic selection programs with the aim to increase feed efficiency, with permanent and cumulative effects (Alford et al. 2006). Feed conversion ratio (FCR) and residual feed intake (RFI) are the most widely used indicators to evaluate feed efficiency in beef and dairy cattle. Berry and Crowley (2013) reported heritability for feed efficiency traits that ranged from 0.06 to 0.62 in growing animals.

As the global population is projected to reach 9 billion by 2050, the improvement of feed efficiency becomes even more urgent (Basarab et al. 2013). Nowadays, limited information on feed efficiency data in young bulls is available (Beauchemin and McGinn 2006; Crowley et al. 2010). It is also worth mentioning that the determination of RFI in lactating cows is somewhat more complicated due to additional sources of variation such as milk production, body maintenance, possible pregnancy, stage of lactation and parity (Connor 2015). Moreover, accurate knowledge of the genetic correlations of productive traits between growing and lactating animals may have long term effects for cattle breeding programs. Indeed, preselection of growing animals for feed efficiency may impact the selection intensity on the breeding goal usually adopted for producing cows (Berry and Crowley 2013). Therefore, the aim of this paper was to characterise dry matter intake, greenhouse gas emissions and feed efficiency of young Holstein bulls.

Materials and methods

Animal management

All animals rearing and handling procedures were carried out in accordance with the European Commission recommendation 2007/526/EC and Directive 2010/63/UE on revised guidelines for the accommodation and care of animals used for experimentation and other scientific purposes. Data were collected between May 2018 and July 2020 on 150 young Holstein bulls, candidates to artificial insemination in the genetic centre of the Associazione Nazionale Allevatori della Razza Frisona, Bruna e Jersey Italiana (ANAFIBJ – Cremona,

Table 1. Ingredients (% as fed) and chemical composition (% of dry matter) of diet distributed to young Holstein bulls involved in the trial.

Diet	%	Standard deviation
Ingredients, % of fed		
Grass hay	42.40	–
Water	32.00	–
Corn meal	5.18	–
Sunflower meal	5.18	–
Wheat bran	4.40	–
Rice feed mills	4.17	–
Alfalfa pellets	1.95	–
Soybean meal	1.46	–
Corn gluten feed	0.67	–
Flaked corn	0.56	–
Calcium carbonate	0.38	–
Dicalcium phosphate	0.38	–
Cane molasses	0.38	–
Sodium bicarbonate	0.38	–
Corn germ meal	0.38	–
Salt	0.13	–
Nutrient composition, % of dry matter		
Dry matter	63.56	2.35
Crude protein	12.86	0.94
Neutral detergent fibre	59.24	3.01
Acid detergent fibre	32.27	2.93
Acid detergent lignin	4.25	0.79
Starch	11.71	1.92
Fat	2.47	0.42
Ashes	8.20	0.68
Ca	0.93	0.02
P	0.36	0.02
Metabolizable energy (Mcal/kg)	2.13	–

Micronutrients provided with a kg of dry matter: vitamin A 10311 IU, vitamin E 64.44 mg, vitamin D3 1676 IU, niacin 83.78 mg, zinc sulphate 52.36 mg, manganese oxide 39.27 mg, ferrous sulphate 23.72 mg, calcium iodate 0.63 mg, sodium selenite 0.26 mg.

Italy). Bulls were subjected to 30-d quarantine after entering the genetic centre and then they spent an adaptation period of 5 days to become familiar with pens equipment. During the experimental period, animals were grouped in multiple pens, according to uniform age and weight. Animals were daily fed ad libitum with a total mixed ratio (TMR) prepared once a day at 8:00 am. Bulls had free access to the feeding stations and water during the whole test period. Chemical composition was measured on samples collected every 60 days. Diet formulation and mean chemical composition are reported in Table 1.

Genetic Centre and data collection

The genetic centre was equipped with five Roughage Intake Control systems (RIC; Hokofarm Group, Voorsterweg, The Netherlands) distributed in three pens. This system allows the recording of individual feed intake (kg/d) and the evaluation of feeding behaviour, including feeding frequency measured as daily feeding events (n/d) and average daily feeding duration (min) (Hegarty et al. 2007). Each sire was monitored by the RIC system from the moment it was electronically recognised until the bull left the system, and this period was defined as a single access. One of the three pens was also equipped with the Automated Head-Chamber System (AHCS; GreenFeed C-Lock Inc., Rapid City, SD, USA), an automated feeding station designed to measure daily CH_4 and CO_2 emissions (g/d) from ruminant's breath (Hristov et al. 2015). A single measurement started and continued during each singular feeding event, until the animal left the feeder.

Data were collected during 10 trials, each involving 15 bulls tested from three to five times along an experimental period of 60 d. At the beginning of each trial, bulls were measured for body weight (BW) and scored for body condition (BCS) by the trained personnel of the ANAFIBJ genetic centre. These traits were periodically recorded during the experiment. Moreover, during the entire experimental period, the RIC system recorded daily feed intake, feeding frequency and daily feeding duration, and during the last 30 days of each trial, the GreenFeed recorded the daily emissions of CO_2 and CH_4. Feeding frequency and daily feeding duration were calculated on data recorded on the same days BW and BCS were assessed. A feeding event was defined as the time spent at the feeding station separated by next one by 300 s or longer (Basarab et al. 2013).

As described by Awda et al. (2013), the average daily gain (ADG, kg/d) of each bull was calculated as the slope of the regression of BW on test days. Dry matter intake (DMI, kg/d) was calculated by multiplying daily feed intake and dry matter content of the ration, whereas expected DMI (EDMI) was obtained from linear regression of DMI on metabolic BW ($BW^{0.75}$) and ADG (Basarab et al. 2003; Fitzsimons et al. 2013; Zhang et al. 2017). Residual feed intake was calculated as the difference between DMI and EDMI (Basarab et al. 2013; Berry and Crowley 2013; Fitzsimons et al. 2013), and FCR was calculated as the ratio of DMI to ADG (Berry and Crowley 2013), where lower scores are more desirable because animals require less feed per kg of BW gain. Finally, CO_2-equivalent was calculated as in Denninger et al. (2020):

$$CO_2\text{−equivalent}\,(g/d) = [CH_4(g/d) \times 20] + CO_2(g/d)$$

Data editing and statistical analyses

The original dataset comprised 549 records of 150 young bulls, sons of 67 sires and 119 dams. Animals with less than 3 records were removed from the dataset. Also, for each trait, values exceeding 2.5 standard deviations (SD) from the mean were set to missing. The final dataset comprised 474 records of 111 young bulls, progeny of 52 sires and 93 dams.

Table 2. Number of records, mean, standard deviation (SD), minimum and maximum of body traits, greenhouse gas emissions, dry matter intake, feed efficiency traits, feeding frequency, and feeding duration of young growing Holstein bulls.

Trait[a]	No of records	Mean	SD	Minimum	Maximum
Age, d	462	276.13	42.09	178.00	405.00
BW, kg	460	298.37	62.58	148.00	468.00
$BW^{0.75}$, kg	466	71.91	11.71	42.43	103.83
ADG, kg/d	467	1.12	0.29	0.43	1.82
BCS	437	3.02	0.23	2.50	3.50
CO_2, g/d	245	5970.48	865.89	3998.58	8093.58
CH_4, g/d	245	220.05	41.16	123.62	318.22
CO_2-equivalent, g/d	247	10,392.11	1595.05	6475.96	14,367.25
DMI, kg/d	430	8.24	2.20	2.46	14.00
EDMI, kg/d	464	8.10	1.47	4.44	12.08
RFI, kg/d	427	0.07	1.54	−4.47	4.46
FCR	425	7.55	2.48	0.99	14.70
Feeding frequency, n/d	378	11.72	4.23	5.00	22.00
Feeding duration, min/d	370	104.09	47.78	28.02	241.00

[a]BW = body weight; $BW^{0.75}$ = metabolic body weight; ADG = average daily gain; BCS = body condition score; CO_2 = carbon dioxide; CH_4 = methane; CO_2-equivalent = carbon dioxide equivalent; DMI = dry matter intake; EDMI = expected dry matter intake; RFI = residual feed intake; FCR = feed conversion ratio.

Pearson correlations coefficients (r) were calculated between residuals obtained from the analysis of the investigated traits using a linear mixed model through the GLIMMIX procedure of SAS software v. 9.4 (SAS Institute Inc., Cary, NC). The model was as follows:

$$y_{ij} = \mu + age_i + bull_j + e_{ij},$$

where y_{ij} is the dependent variable (BW, ADG, BCS, CO_2, CH_4, CO_2-equivalent, DMI, EDMI, RFI, FCR, feeding frequency, and feeding duration); μ is the overall intercept of the model; age_i is the fixed effect of the linear covariate of age of bull on y; $bull_j$ is the random effect of the jth bull (j = 1–111) $\sim N(0, \sigma^2_{bull})$, where σ^2_{bull} is the bull variance; and e_{ij} is the random residual $\sim N(0, \sigma^2_e)$, where σ^2_e is the residual variance.

Residual feed intake was divided in two classes, one including negative values (low RFI) and one including positive values (high RFI). Feed conversion ratio was divided in two classes, the first (low FCR) and the second (high FCR) included values below and above the mean, respectively. In order to evaluate the effect of RFI and FCR on the studied traits, the same linear mixed model described previously was used but with the addition of the class effects of RFI and FCR in two separate analyses. Significance was set at $p < .05$.

Results and discussion

Descriptive statistics

Age, BW, $BW^{0.75}$, ADG and BCS of young Holstein bulls averaged 276.13 d, 298.37 kg, 71.91 kg, 1.12 kg/d and 3.02, respectively (Table 2). Average daily gain was greater compared with values reported by Byrne et al. (2018) who administered a low plan nutrition diet to Holstein-Friesian bulls from 2 weeks of age until puberty. On the other hand, ADG of the present study was similar to ADG of bull calves fed a high plan nutrition diet in the study of Byrne et al. (2018) and in agreement with Calo et al. (1973). No BCS data were available in recent literature for Holstein Friesian bulls, however average BCS observed in the present study was comparable to that reported by Roche et al. (2006) and Buckley et al. (2003), who studied BCS in 113 and 6433 Holstein-Friesian dairy cows, respectively.

Means of GHG emissions were 5970.48, 220.05 and 10,392.11 g/d for CO_2, CH_4 and CO_2-equivalent, respectively (Table 2). Beauchemin et al. (2009) reported that daily CH_4 production typically ranges from 200 to 500 g/d for lactating dairy cows and 50 to 300 g/d for beef cattle. In a review of 89 scientific papers published between 1992 and 2015, Liu et al. (2017) reported higher CH_4 emissions, which are likely attributable to higher daily DMI of the animals. Average CH_4 emissions from animals involved in the present study were lower than those reported for other cattle breeds such as Angus bulls and heifers intended for meat production (Beauchemin and McGinn 2006; Hegarty et al. 2007). Methane emissions ranged from 123.62 g/d to 318.22 g/d (Table 2), which was similar to the range reported by Hegarty et al. (2007) in steers selected for low and high RFI.

Average DMI was 8.24 kg/d and it ranged from 2.46 to 14.00 kg/d (Table 2). This value was slightly lower than the mean DMI observed by Basarab et al. (2013) for young bulls (9.05 kg/d) and by Awda et al. (2013) for growing beef bulls (9.79 kg/d). Means of EDMI and RFI were 8.10 kg/d and 0.07, respectively, the latter being slightly greater than the average RFI obtained by Fitzsimons et al. (2013) in beef heifers ranked as high, medium and low RFI. Arthur et al. (2001) observed similar RFI mean (0.05) in Angus bulls and heifers. Feed conversion ratio averaged 7.55 (SD = 2.48), i.e., close to findings of Archer and Bergh (2000) in four beef cattle breeds (FCR from 6.52 to 7.28) and Nkrumah et al. (2007) in beef cattle (FCR = 7.29). Also, the Iowa State University Digital Repository (2013) reported that typically FCR ranges from 4.50 to 7.50 in beef cattle. Crowley et al. (2010) reported FCR of 6.46 in Limousine bulls, and Cassady et al. (2016) observed FCR of 5.58 and 5.61 in Charolaise heifers during the growing and finishing periods, respectively, which are lower compared to average FCR obtained for Holstein young bulls of the current study. In the present study,

Table 3. Pearson correlations between residuals of body traits, greenhouse gas emissions, dry matter intake, feed efficiency traits, feeding frequency and feeding duration.

Trait[a]	ADG	BCS	CO_2	CH_4	CO_2-equivalent	DMI	RFI	FCR	Feeding frequency	Feeding duration
BW	0.02	0.41***	0.51***	0.24***	0.35***	0.49***	0.27***	0.46***	0.28***	0.23***
ADG		−0.01	0.03	0.04	0.03	0.07	−0.02	−0.21***	0.03	0.02
BCS			0.16*	0.16*	0.14*	0.22***	0.12*	0.17**	0.08	0.07
CO_2				0.62***	0.88***	0.36***	0.14*	0.31***	0.26***	0.18*
CH_4					0.90***	0.25***	0.12*	0.20**	0.10	0.07
CO_2-equivalent						0.29***	0.14*	0.24***	0.16*	0.11
DMI							0.86***	0.86***	0.45***	0.36***
RFI								0.79***	0.37***	0.30***
FCR									0.45***	0.37***
Feeding frequency										0.80***

[a]BW = body weight; ADG = average daily gain; BCS = body condition score; CO_2 = carbon dioxide; CH_4 = methane; CO_2-equivalent = carbon dioxide equivalent; DMI = dry matter intake; RFI = residual feed intake; FCR = feed conversion ratio.
*$p < .05$, **$p < .01$, ***$p < .001$.

the average feeding frequency was 11.72 visits per day, and the average feeding duration was 104.09 min/d. In a study on beef steers, Basarab et al. (2003) reported an average feeding frequency of 8.6 visits per day and an average feeding duration of 87.9 min/d. Refat et al. (2018) working on mid-lactating dairy cows, obtained an average feeding frequency of 9.1 visits per day and an average feeding duration of 225.5 min/d, which is considerably greater compared with the results of the present study.

Correlations

Body weight was moderately positively associated with BCS ($r = 0.41$, $p < .001$) and DMI ($r = 0.49$, $p < .001$; Table 3). Nieuwhof et al. (1992) reported phenotypic correlations between BW and roughage intake of 0.72 for growing heifers. Body weight was weakly positively associated with CH_4 ($r = 0.24$, $p < .001$) and moderately correlated to CO_2-equivalent and CO_2 ($r = 0.35$ and $r = 0.51$, respectively; $p < .001$). The present study highlighted weak to moderate unfavourable associations between BW and feed efficiency; indeed, the correlations of BW with RFI and FCR were 0.27 and 0.46, respectively ($p < .001$; Table 3), which agreed with values of 0.34 (BW-FCR) and 0.24 (BW-FCR) reported by Crowley et al. (2010). Despite significant, the unfavourable relationships between BCS and GHG were weak ($r = 0.14$–0.16; Table 3). Average daily gain and RFI were uncorrelated ($r = -0.02$; Table 3), in agreement with the estimate reported by Van Arendonk et al. (1991) for lactating dairy cows ($r = -0.01$), whereas a favourable, despite weak, association was observed between ADG and FCR ($r = -0.21$, $p < .001$), indicating that, on average, faster growing animals are more efficient than lower growing animals.

Pearson correlations between GHG ranged from 0.62 to 0.90 ($p < .001$; Table 3). Dry matter intake was weakly to moderately and unfavourably associated with GHG ($r = 0.25$–0.36, $p < .001$), in agreement with Beauchemin et al. (2020) who reported that CH_4 production is mainly influenced by DMI further than animal feeding behaviour and feed composition and fermentability. Overall, correlations between GHG and feed efficiency traits were weak and unfavourable. In particular, Pearson correlations between GHG and RFI ranged from 0.12 to 0.14 ($p < .05$), suggesting that, on average, more efficient animals are endowed with lower GHG emissions. Similarly, correlations between GHG and FCR ranged from 0.20 (CH_4, $p < .01$) to 0.31 (CO_2, $p < .001$). De Haas et al. (2011) estimated stronger correlation ($r = 0.72$) between predicted CH_4 and RFI for lactating Holstein cows. De Haas et al. (2011) and Cassandro et al. (2013) reported that the genetic correlation between feed efficiency and enteric CH_4 emissions in dairy cows varied from 0.18 to 0.84.

Dry matter intake was strongly positively associated with RFI and FCR ($r = 0.86$, $p < .001$), in agreement with Basarab et al. (2013), who reported moderate to strong relationships between RFI and feed intake ($r = 0.47$–0.72), and Cassady et al. (2016), who estimated correlations of 0.56 and 0.63 between DMI and RFI for Charolais crossbred heifers during growing and finishing periods, respectively. Berry and Crowley (2013) reported a phenotypic correlation between FCR and feed intake in the range between −0.29 and 0.98. Residual feed intake was strongly correlated with FCR ($r = 0.79$, $p < .001$). As regards the phenotypic association between RFI and FCR, the scientific literature reports estimates from 0.46 to 0.70 between feed intake and FCR (Arthur et al. 2001; Basarab et al. 2003; Basarab et al. 2013).

Positive correlations were observed between BW and feeding animal behaviour. In particular, the association between BW and feeding frequency was 0.28 ($p < .001$), and between BW and feeding duration was 0.23 ($p < .001$), suggesting that, on average, heavier animals tended to spend more time in the feeder and tended to have more visits. Feeding behaviour was

Table 4. Least squares means (standard error) of body weight (BW), dry matter intake (DMI), greenhouse gas emissions, feeding frequency, and feeding duration in low and high classes of residual feed intake (RFI) and feed conversation ratio (FCR).

	RFI		FCR	
Trait	Low	High	Low	High
BW, kg	293.86^b (6.09)	306.68^a (6.07)	290.11^b (5.92)	310.17^a (5.93)
DMI, kg/d	6.86^b (0.16)	9.36^a (0.16)	6.80^b (0.19)	9.34^a (0.19)
CO_2, g/d	5848.90^b (88.52)	6068.98^a (86.77)	5806.00^b (90.83)	6160.71^a (91.14)
CH_4, g/d	214.08^b (4.30)	224.05^a (4.13)	214.78^b (4.60)	226.34^a (4.70)
CO_2-equivalent, g/d	10,156.00^b (163.08)	10,534.00^a (158.48)	10,152.00^b (174.32)	10,662.00^a (176.34)
Feeding frequency, n/d	10.27^b (0.05)	12.83^a (0.05)	10.40^b (0.05)	12.61^a (0.05)
Feeding duration, min/d	92.07^b (0.05)	113.12^a (0.05)	90.29^b (0.05)	112.91^a(0.05)

Least squares means with different superscript letters within a row are significantly different ($p < .05$).

also positively associated with GHG emissions, with correlation estimates from 0.07 to 0.26 ($p < .05$), suggesting that animals with lower feeding frequency and duration had mitigated GHG emissions. Feeding frequency and feeding duration were moderately positively associated with DMI ($r = 0.45$ and 0.36, $p < .001$), RFI ($r = 0.37$ and 0.30, $p < .001$) and FCR ($r = 0.45$ and 0.37, $p < .001$), indicating that animals with lower feeding frequency and feeding duration ingested less feed but were more efficient. Similarly, Basarab et al. (2013) reported that more efficient animals visited less the feeder and had shorter feeding duration when compared to less efficient animals.

Least squares means

Least squares means of BW, DMI, CO_2, CH_4, CO_2-equivalent, feeding frequency and feeding duration in low and high classes of RFI and FCR are summarised in Table 4. Low RFI bulls were 13 kg lighter than high RFI bulls ($p < .05$), which agrees with Awda et al. (2013) and Alemu et al. (2017). Dry matter intake was 2.50 kg/d greater in high than low RFI animals ($p < .05$), resembling the result of Hegarty et al. (2007), who reported that animals with low RFI ingested 41% less DMI than animals with high RFI. Low RFI emitted around 10 g/d less enteric CH_4 than high RFI bulls ($p < .05$; Table 4). Alemu et al. (2017) reported similar results for enteric CH_4 emissions measured on 16 crossbred heifers through AHCS. Fitzsimons et al. (2013) quantified enteric emissions through SF_6 metabolic chamber and reported that low RFI group of animals produced less GHG. Hegarty et al. (2007) observed 25% less daily CH_4 emission in low RFI than high RFI Angus steers. As regards feeding behaviour traits, low RFI bulls tended to reduce the feeding frequency and feeding duration compared with high RFI bulls ($p < .05$; Table 4), which agrees with Basarab et al. (2003) who reported lower feeding frequency duration for animals with low RFI.

Low and high classes of FCR resembled the trend of low and high classes of RFI, i.e., low FCR animals had lower BW, lower DMI, emitted less CO_2, CH_4 and CO_2-equivalent, visited the feeder less frequently and had a lower feeding duration than high FCR animals ($p < .05$). The FCR is traditionally the most common measure of feed efficiency in beef cattle (Berry and Crowley 2013) and animals with lower FCR are more efficient than higher FCR animals. Recent research on feed efficiency showed that efficient animals reduced feeding duration and feeding frequency (Rauw 2012; Basarab et al. 2013). Those authors hypothesised that this might be associated to the reduction of BW and DMI on efficient animals.

Results of the present study in terms of feed efficiency calculated through RFI and FCR need further investigation. For example, the assessment of rumen volatile fatty acids, which are produced by carbohydrates and amino acids fermentation, should be evaluated since they are closely related to hydrogen and CH_4 production (Wang et al. 2014). In particular, acetic to propionic acid ratio is expected to be lower in more efficient animals. Indeed, this ratio typically varies from approximately 0.9 to 4, where lower values correspond to lower CH_4 production (Johnson and Johnson 1995).

Conclusions

Results of the present study demonstrated the existence of phenotypic variation of feed efficiency, feed intake, body traits and GHG emissions in young Holstein bulls intended for artificial insemination. Also, this study provided experimental evidence on the association between feed efficiency and GHG: more efficient animals consumed less feed and reduced GHG emissions. Our intention is to record some of the daughters of these bulls in order to re-estimate genetic correlations between bulls and cows, to assess the heritability of studied traits and ultimately to achieve GHG mitigation through genetic selection.

Disclosure statement

The authors declare that there is no conflict of interest associated with the paper. The authors alone are responsible for the content and writing of this article.

Data availability statement

None of the data were deposited in an official repository. The data that support the findings presented in this study are available from the first author or corresponding author upon reasonable request.

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