ARCHIVES OF ANIMAL NUTRITION
2024, VOL. 78, NO. 1, 16–29
https://doi.org/10.1080/1745039X.2023.2292424

Taylor & Francis
Taylor & Francis Group

Check for updates

Intake, digestibility, energy and nitrogen utilisation, and enteric methane emission in Holstein and Girolando-F1 cows during the transition period

João Pedro Matiello [a], Anne Rosi Guadagnin [b,c], Elissa Forgiarini Vizzotto [d], Sheila Cristina Bosco Stivanin [d], Guilherme Heisler [d], Arthur Fernandes Bettencourt [d], Mariana Magalhães Campos [e], Thierry Ribeiro Tomich [e], Fernanda Samarini Machado [e], Luiz Gustavo Ribeiro Pereira [e] and Vivian Fischer [d]

[a]Department of Animal Science, Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil; [b]Department of Animal Science, University of Wisconsin, Madison, WI, USA; [c]Schothorst Feed Research, Lelystad, Netherlands; [d]Department of Animal Science, Federal University of Rio Grande do Sul, Porto Alegre, Brazil; [e]Brazilian Agricultural Research Corporation – Embrapa Dairy Cattle, Juiz de Fora, Brazil

ABSTRACT

This study aimed to evaluate intake, energy and nitrogen balance as well as methane emission in Holstein and ½ Holstein ½ Gyr (Girolando-F1) cows during the transition period. Twenty-four cows (12 Holstein and 12 Girolando-F1) were used to evaluate feed intake, apparent digestibility, heat production and methane emission, carried out in two periods: from 28 to 19 days pre-calving and from 15 to 23 days post-calving. A completely randomised design was used and data were analysed by ANOVA within periods (pre- and post-calving) considering the main effect of genetic groups. Girolando-F1cows presented greater body condition score (BCS) compared with Holstein. During pre-calving, there were no differences between genetic groups, except for highest heat production per kilogram of metabolic body weight for Holstein cows. After calving, Holstein cows had greater intake of DM, nitrogen, NDF per kg of BW and produced more heat per kg of metabolic body weight. Holstein cows yielded more milk and fat-corrected milk ($FCM_{4\%}$) compared with Girolando-F1 cows. Holstein cows presented higher methane emission per unit of BW and of metabolic weight. Emissions of enteric methane per kilogram of milk and per kilogram of $FCM_{4\%}$ tended to be lower for Holstein compared with Girolando-F1 cows. Nitrogen and energy retention were similar for both Holstein and Girolando-F1 at pre- and post-calving. Despite differences in BCS, DMI, and milk yield, Girolando-F1 and Holstein cows present overall similar energy efficiency, albeit Holstein cows tended to present less methane emission per kg of eligible product (milk).

ARTICLE HISTORY
Received 31 July 2023
Accepted 1 December 2023

KEYWORDS
Bos indicus crossbred; bos taurus; dairy cows; efficiency; metabolism

CONTACT Vivian Fischer vivianfischer62@gmail.com

This article has been corrected with minor changes. These changes do not impact the academic content of the article.

Supplementary data for this article can be accessed at https://doi.org/10.1080/1745039X.2023.2292424.

© 2024 Informa UK Limited, trading as Taylor & Francis Group

1. Introduction

The introduction of European dairy breeds in the tropical environment eventually brought adaptability problems to these animals. Animals that are well-adapted to elevated temperatures are characterised by small loss of production during stress periods, with better reproductive efficiency, greater disease resistance, longer longevity and lower mortality than non-adapted animals (McManus et al. 2009). Highly productive European-origin animals may produce milk less efficiently than heat-resistant animals when raised in places of high temperature and humidity (Mellado et al. 2011). The use of *Bos taurus* and B*os indicus* crossbred animals is a viable alternative, both economically and in relation to animal welfare (Madalena et al. 2012) to overcome environmental constrains prevailing in the tropics. *Bos indicus* and their crossbreed with *Bos taurus* animals represent more than 70% of Brazil's dairy cows. In Holstein × Gyr crosses, increasing proportion of Gyr genes decreased milk yield, but because of adaptation, heterosis and management, they are able to express productive potential (Vieira et al. 2022).

Recently, Villanueva et al. (2023) reported similar enteric CH_4 emissions among genetic groups (F1: 50% Jersey × 50% Gyr and Triple cross: 50% Jersey × 31% Holstein × 19% Sahiwal and Jersey cows), although F1 cows tended to show lower enteric CH_4 emission and annual mean methane conversion factor, compared to those with more *Bos taurus* genes. Sguizzato et al. (2020) evaluated the efficiency of use of metabolisable energy for maintenance of non-pregnant and pregnant Gyr × Holstein crossbred cows, and observed very similar values for both groups, of 62.4% and 62.5%, respectively. The efficiency of metabolisable energy utilisation for gain and pregnancy was 41.9% and 14.1%, respectively. The authors found that nonlinear equations to estimate net energy requirements for pregnancy were more adequate for Holstein × Gyr cows than the current NRC equation (National Research Council 2001).

Moreover, Carvalho et al. (2018) evaluated two genetic groups Gyr and Holstein × Gyr (Girolando-F1) crossbreds and reported that Girolando-F1 presented higher intake values for gross energy (GEI), metabolisable energy (MEI) and digestible energy (DEI). Gross energy lost in faeces was higher in Girolando-F1 (23.7% GEI) compared with Gyr (20.5%) cows. Energy lost as methane and urine was similar between the groups. The overall metabolisability (q) was 0.67, and the efficiency of converting ME to NE (k) was 0.56. There was no difference in the energy requirements for maintenance between genetic groups (426.6 MJ/kg $BW^{0.75}$ average value). The energy requirements for lactation were higher in Girolando-F1animals due to the greater volume of milk produced, as there was no difference in energy requirements for production per kilogram of milk. Albeit the increasing importance of crossbred dairy cattle in several countries, there is still much less information about their physiology, metabolism and nutrient requirements during the transition period compared with European-origin cows (Carvalho et al. 2018). Recently some studies highlighted some differences in the metabolites profile in the blood between Holstein and Girolando-F1 during the transition period (Angelo et al. 2022), in health and behaviour (Stivanin et al. 2021), in milk yield and composition as well oxidative stress (Vizzotto et al. 2021). Conversely, Kolling et al. (2018) did not report significant differences between Holstein and Girolando-F1 for milk yield, apparent total digestibility, heat production and methane emission.

Therefore, we tested the hypothesis that genetic group influences digestibility, energy utilisation, enteric methane emission and nitrogen balance during the transition period. The present study aimed to evaluate the feed intake, apparent digestibility, nitrogen and energy balance as well as enteric methane emissions in Holstein and Girolando-F1 cows during the transition period.

2. Material and methods

The experiment was carried out in the facilities of the Multiple Complex of Livestock Bioefficiency and Sustainability of the Brazilian Agricultural Research Corporation (EMBRAPA), in Coronel Pacheco, Minas Gerais, Brazil. The Ethics Committee of Embrapa Dairy Cattle, protocol number 25/2015, and of the Federal University of Rio Grande do Sul, protocol number 29,838, approved all procedures.

2.1. Animals and housing

Twenty-four primiparous cows (12 Holstein and 12 Girolando-F1 (½ Holstein × ½ Gyr)), blocked by breed were divided into two groups and fed total mixed rations (TMR) at pre- and post-calving. Composition of TMRs is present in *Supplementary Table S1*.

The animals were housed in individual tie-stall pens (2.5 × 1.2 m) with rubber bedding (WingFlex, Kraiburg TPE GmbH & Co., Walkraiburg, Germany). During the whole trial, animals had *ad libitum* access to water. The animals were fed individually twice a day at 8:00 a.m. and 4:00 p.m., and the leftovers were removed and weighed every day prior to a new TMR delivery. Feed intake as well *in vivo* digestibility, nitrogen and energy balance were measured during pre- and post-calving periods: the first began at d-28 before estimated calving (pre-calving period) and the second began at d15 after calving (post-calving period).

Cows were weighed using an automatic electronic scale (WD-1000, Intergado Ltd., Contagem, Minas Gerais, Brazil), installed in the access to the drinker and further averaged per animal and per day. The body condition (BCS) was scored weekly during the *prepartum* period, at calving and on postpartum, by two previously trained raters.

2.2. Dry matter intake and digestibility (collection of faeces, urine and feed samples)

Digestion essay was run on two periods: between d-28 and d-21 pre-calving and between d15 and d22 post-calving. Faeces were collected at the last 3 days of each period, weighed twice a day at 08:30 and 16:30, and 0.5 kg were sampled. Samples of faeces and leftovers collected were pooled by animal and period, based on their daily amount.

Total urine collection was performed using Foley intravesical probes (Rüsch Foley Catheter, Teleflex Medical Europe Ltd, Co. Westmeath, Ireland) on the last 2 days of each period. The probes were connected to hoses that carried the urine into polyethylene plastic containers immersed in ice. After 24 h of collection, the urine was weighed and its volume measured. After being homogenised, 50 ml was sampled and stored at −10°C until determination of energy and nitrogen content.

TMR and leftover samples were taken daily throughout the whole trial and stored at −10°C for further processing and analyses. Samples of corn and sorghum silage, concentrate, leftovers and faeces were analysed for dry matter and mineral content according to method 930.15 described in AOAC (1990); gross energy was determined using an adiabatic bomb calorimeter (IKA – C5000, IKA Works, Staufen, Germany); crude protein determined following the method 984.13 described in AOAC (1990); ether extract was analysed using a Soxhlet type apparatus and neutral detergent fibre was determined by the method described by Van Soest et al. (1991). The urine samples were analysed for gross energy and nitrogen content in the same way as the other samples.

Feed intake was calculated as the difference between the amounts offered in the present day and the leftovers in the day after. The digestibility coefficients were determined by the following equation: digestibility (%) = ((amount of DM ingested, or the amount of CP or NDF or GE in the ingested food – amount of DM, CP, NDF and GE excreted in the faeces)/amount of DM, CP, NDF and GE ingested)). Apparent digestibility coefficients for DM, NDF were also expressed as dDM and dNDF in the text. Nitrogen balance was calculated according to the equation: N Retained = N ingested - (Fecal N + Urinary N) for dry cows and N Retained = (N ingested - (Fecal N + Urinary N + Milk N) for lactating cows.

2.3. Respirometry and enteric methane emission

After apparent digestibility essay (between d-20 and d-19 pre-calving and between d23 and d24 post-calving), oxygen uptake (O_2), and carbon dioxide (CO_2) and enteric methane (CH_4) emissions were measured using four open-system respiratory chambers according to specifications and procedures described by Machado et al. (2016). Briefly, animals were previously adapted to halters and handling at respiratory chambers. Cows were milked at 07:30 and 15:30 and fed at 08:00 and 16:00. From the moment of delivery of the TMR, the cows entered the chamber in random order and each cow was kept in the chamber for 22 hours a day, on two days, totalling 2 days of measurements for each cow per period (pre and postpartum). Cows left the respiratory chamber for milking. The animals were weighed before and after entering the chambers.

Two pairs of chambers (3.68 m long, 2.56 m wide and 2.24 m high) were used, with controlled climate, maintaining temperature and humidity in the range of 24°C and 60%, respectively. The chambers had windows on both sides to allow the animals to maintain visual contact with the outside area. For the animals' safety, each chamber was equipped with an emergency hatch, closed by a magnet that could open automatically in case of power outages, floods, extreme temperatures or excess CO_2.

An air outlet with filter box (CSL-851-200HC, Solberg Manufacturing Inc., Itasca, USA) was part of each chamber, with air being continuously drawn into the chamber by a sealed rotary pump connected to a pressure regulator mass flow (FlowKit model FK-500, Sable Systems International, Las Vegas, NV, USA). Air from all chambers and a sample of ambient air were analysed for their concentrations of O_2, CO_2, CH_4; monitoring took place over a cyclical period of 20 minutes. When animals enter the chambers, gas concentration in the chamber was allowed to equilibrate for 1 hour after cows entered the chamber from milking. Analysers were calibrated daily and chamber recovery values were 99% and 98% for CO_2 and CH_4, respectively.

Calibration of the CO_2 and CH_4 analysers (zero and span) was performed daily before starting each measurement O_2 and water vapour analysers were calibrated once a week. Nitrogen gas (99.99%) was used to zero the CO_2, CH_4 and O_2 analysers and for span calibration of CO_2 and CH_4 mixed gas was used (0.5% CO_2, 0.1% CH_4 in N_2 as carrier). The O_2 analyser was calibrated with dry ambient air, purified from water with magnesium perchlorate, as it has an almost constant concentration of 20.95% of O_2. The zero value of the water vapour analyser was reached with dry air, and the span value was calculated following Lighton's Equation (2008): WVP = BP × [(FiO_2 – FiO_2)/FiO_2], where WVP is the water vapour pressure in the same units as barometric pressure (kPa); BP is barometric pressure; and FiO_2 and FiO_2 are fractional concentrations of O_2 in dry and humid ambient air, respectively.

A system-wide recovery test was performed immediately prior to the start of the trial in each of the pre- and postpartum weeks by injecting known volumes of CO_2 (99.99%) and CH_4 (99.99%) into each chamber using a metre portable mass flowmeter with totaliser function (MC-50SLPM-D, Alicat Scientific Inc., Tucson, AZ). Data acquisition and analyses were performed using the Metasys software (version 5.1.3.0400; Johnson Controls Inc., Milwaukee, WI) which allows the calculation of the O_2 consumption rate and CO_2 and CH_4 production. Within each 22 h period, the gas exchanges obtained for 200 sec cycle were used to calculate the daily exchanges, extrapolating the obtained data. HP was calculated according to Brouwer (1965).

2.4. Energy partitioning

The daily gross energy intake (GEI) as well as faecal (GEFe) and urinary (GEUr) energy output were calculated multiplying the dry matter amount of feed intake, faecal and urine production by their respective gross energy content. Digestible energy intake (DEI) was calculated as the difference between gross energy intake and gross energy losy in faeces, GEFe. Metabolizable energy intake (MEI) was calculated as the difference between digestible energy intake (DEI) and the sum of gross energy lost in urine (GEUr) and in enteric methane (GEMe), assumed as equivalent as 9.45 Kcal/L (Brouwer 1965). Energy retention (Er) was calculated as the difference between MEI and heat production (HP). HP was determined based on O_2 consumption [L/day], CO_2 and CH_4 emission [L/day] and urinary nitrogen excretion [g/day] using the Brouwer equation (Brouwer 1965). Moreover, HP was also expressed per kg of $BW^{0.75}$.

2.5. Statistical analyses

Statistical analyses was performed using SAS software (version 9.4, SAS Institute Inc., Cary, NC, USA). Data were analysed using the ANOVA and the MIXED procedures, considering the animal as an experimental unit, and the genetic groups (Holstein and Girolando-F1) as fixed effect, according to the following model:

$$Y_{ijk} = \mu + GG_i + E_{ij},$$

whereY_{ijk} is the dependent, continuous variable; μ is the overall mean; $GG_i$is the fixed effect of genetic group; and E_{ij} is the residual error. Animal and residual error were considered as random effects. Statistical differences were declared significant at $p \leq 0.05$ and tendency at $0.05 < p \leq 0.10$.

3. Results

3.1. Pre-calving period

Girolando-F1 cows had higher ($p < 0.05$) body condition score (BCS) compared with Holstein cows at pre- and post-calving (Table 1). Holstein cows tended to have greater feed intake ($0.05 < p \leq 0.10$) expressed per kg of BW than Girolando-F1 cows. Genetic group did not affect any of the variables measured for nitrogen balance and energy partition and efficiency, except the higher heat production per kg of $BW^{0.75}$ in Holstein compared with Girolando-F1 cows (Tables 2 and 3).

Table 1. Average of body weight (BW) and body condition score (BCS) during pre-calving and post-calving periods in Holstein and Girolando-F1 cows.

	Genetic Group (GG)			*p*-value
Variables	H	F1	SEM	GG
Pre-calving				
BW (kg)	784	794	21.5	NS
BCS (1 to 5)	4.0b	4.3a	0.05	**
Post-calving				
BW (kg)	661	716	23.0	NS
BCS (1 to 5)	3.5b	3.9a	0.09	**

Note. SEM = standard error of the mean; NS = not significant ($p > 0.10$); **= $p < 0.01$; means followed by different letters in the same line differ by F-test ($p < 0.05$).

Table 2. Average values for intake, digestibility and nitrogen balance during the pre-calving period in Holstein and Girolando-F1 cows.

	Genetic Group (GG)			*p*-value
Variables	H	F1	SEM	GG
Intake				
DMI	11.8	11.1	0.42	NS
DMI_{BW}	15.1	12.9	0.60	t
NDFI	4.5	4.5	0.13	NS
$NDFI_{BW}$	5.9	5.3	0.20	NS
Apparent whole tract digestibility coefficients (%)				
dDM	59	59	9.5	NS
dNDF	31	36	1.5	NS
Nitrogen balance				
NI	211	193	8.1	NS
Nf	91.2	82.4	3.77	NS
Nd	120	100	7.6	NS
Nu	68.3	63.3	2.78	NS
Nr	36.5	30.0	5.43	NS
Nr/Nd	0.30	0.30	0.102	NS

Note. DMI = dry matter intake [kg/d]; NDFI = neutral detergent fibre intake [kg/d]; DMI_{BW} = dry matter intake as proportion of BW [g/kg BW]; $NDFI_{BW}$ = neutral detergent fibre intake per kg of BW [g/kg BW]; dDM = apparent digestibility coefficient for DM [%]; dNDF = apparent digestibility coefficient for NDF [%]; NI = nitrogen intake [g/d]; Nf = faecal nitrogen [g/d]; Nd = digestible nitrogen [g/d]; Nu = urine nitrogen [g/d]; Nr = retained nitrogen [g/d]; SEM = standard error of the mean; NS = not significant ($p > 0.10$); t = trend ($0.05 < p \leq 0.10$).

Table 3. Energy partition in Holstein and Girolando-F1 cows fed TMR during the pre-calving period.

	Genetic Group (GG)			p-value
Variable	H	F1	SEM	GG
Energy partition				
GEI	233	222	8.0	NS
GEf	87.0	80.0	3.04	NS
DEI	139	133	6.1	NS
GEu	3.0	2.8	0.13	NS
GE_{CH4}	13.5	14.5	0.66	NS
MEI	106	98.0	7.36	NS
$HP_{BW}{}^{0.75}$	0.75a	0.67b	0.169	**
HP	121	119	2.2	NS
Er	−1.2	−2.2	5.73	NS
DE/GE	0.60	0.62	0.009	NS
ME/GE	0.50	0.52	0.008	NS
ME/DE	0.86	0.85	0.009	NS
Methane emissions				
CH_4	245	262	11.9	NS
$CH_{4\ BW}$	0.34	0.33	0.009	NS
$CH_{4\ BW}{}^{0.75}$	1.7	1.7	0.07	NS
$CH_{4\ DM}$	23.2	27.0	1.98	NS
$CH_{4\ NDF}$	55.5	61.3	2.87	NS
CH_{4dDM}	40.5	45.2	3.27	NS
$CH_{4\ dNDF}$	188	178	12.8	NS

Note. GEI = gross energy intake [MJ/d]; GEf = faecal energy [MJ/d]; DEI = digestible energy intake [MJ/d]; GE_{CH4} = energy in methane [MJ/d]; MEI = metabolisable energy intake [MJ/d]; $HP_{BW}{}^{0.75}$ = heat production per unit of metabolic weight [MJ/d/kg $BW^{0.75}$]; HP = heat production [MJ/d]; Er = retained energy [MJ/d]; DE/GE = digestibility; ME/GE = metabolizability; CH_4 = daily methane emission [g/d]; CH_{4BW} = daily methane emission per unit of BW [g/kg BW]; $CH_{4BW}{}^{0.75}$ = daily methane emission per unit of metabolic weight [g/kg $BW^{0.75}$]; CH_{4DM} = daily methane emission per unit of DMI [g/kg DMI]; CH_{4NDFi} = daily methane emission per unit of NDFI [g/kg NDFi]; CH_{4DDM} = daily methane emission per unit of digestible dry matter [g/kg digestible DM]; CH_{4NDFd} = daily methane emission per unit of digestible NDF [g/kg of digestible NDF]; SEM = standard error of the mean; NS = not significant ($p > 0.10$); ** = $p < 0.01$; means followed by different letters in the same line differ by Tukey's test ($p < 0.05$).

3.2. Post-calving period

Girolando-F1 cows had higher ($p < 0.05$) BCS compared with Holstein cows (Table 1). Holstein cows had greater feed intake ($p < 0.05$) expressed as daily absolute value or as a proportion of BW as well as NDFI as a proportion of BW compared with Girolando-F1. Holstein cows also ingested ($p < 0.05$) more nitrogen and tended ($0.05 < p \leq 0.10$) to excrete more nitrogen in the faeces compared with Girolando-F1 cows (Table 4).

Holstein cows produced more heat per $BW^{0.75}$ ($p < 0.05$) than Girolando-F1 cows. Holstein cows tended ($0.05 < p \leq 0.10$) to excrete more energy in faeces than Girolando-F1 cows (Table 5). Methane emissions calculated per BW unit (CH_4/BW) and per metabolic weight unit ($CH_4/BW^{0.75}$) were higher ($p < 0.05$) in Holstein compared with Girolando-F1 cows, while we observed a tendency ($0.05 <$ $p \leq 0.10$) for higher methane emission per kg of milk and per unit of $FCM_{4\%}$ in Girolando-F1 compared with Holstein cows (Table 5). Daily total methane emission and methane per kg of DMI were similar for both genetic groups at pre- and post-calving periods. Holstein cows yielded more ($p < 0.05$) milk, FCM and energy in milk than Girolando-F1 cows (Table 5).

Table 4. Average values for intake, digestibility and nitrogen balance during the post-calving period in Holstein and Girolando-F1 cows offered TMR.

	Genetic Group (GG)			*p*-value
Variables	H	F1	SEM	GG
Intake				
DMI	20.3a	17.1b	0.77	*
DMI_{BW}	26.7a	18.1b	1.40	**
NDFI	7.1	6.1	0.29	NS
$NDFI_{BW}$	9.3a	6.6b	0.55	**
Apparent whole tract digestibility coefficients (%)				
dDM	69	70	8.3	NS
dNDF	51	53	2.4	NS
Nitrogen balance				
NI	365a	260b	24.3	*
Nf	109	83.8	7.56	t
Nd	265	185	23.1	NS
Nu	245	222	10.4	NS
Nr	−41	−78	24.0	NS
Nr/Nd	−0.16	−0.42	0.150	NS

Note. DMI = dry matter intake [kg/d]; NDFI = neutral detergent fibre intake [kg/d]; DMI_{BW} = dry matter intake as proportion of BW [g/kg BW]; $NDFI_{BW}$ = neutral detergent fibre intake per kg of BW [g/kg BW]; dDM = apparent digestibility coefficient for DM; dDE = apparent digestibility coefficient for energy; dNDF = apparent digestibility coefficient for NDF; NI = nitrogen intake [g/d]; Nf = faecal nitrogen [g/d]; Nd = digestible nitrogen [g/d]; Nu = urine nitrogen [g/d]; Nr = retained nitrogen [g/d]; SEM = standard error of the mean; NS = not significant ($p >$ 0.10); t = trend (0.05 $< p \leq$ 0.10); *= $p \leq 0.05$; **= $p < 0.01$; means followed by different letters in the same line differ by Tukey's test ($p < 0.05$).

Table 5. Energy partition in Holstein (H) and Girolando-F1 (F1) cows fed TMR during the post-calving period.

	Genetic Group (GG)			*p*-Value
Var/Trat	H	F1	SEM	GG
Energy partition				
GEI	294	256	13.1	NS
GEf	98.3	80.7	5.06	t
DEI	211	190	10.0	NS
GEu	5.3	4.6	0.33	NS
GE_{CH4}	22.3	19.6	0.92	NS
MEI	189	166	11.3	NS
$HP_{BW}{}^{0.75}$	0.92a	0.75b	0.132	**
HP	127	121	5.6	NS
Er	−0.38	−19.0	9.082	NS
DE/GE	0.70	0.72	0.009	NS
ME/GE	0.53	0.54	0.002	NS
ME/DE	0.87	0.87	0.009	NS
Methane emissions				
CH_4	404	356	17.1	NS
$CH_{4\ BW}$	0.53a	0.38b	0.030	*
$CH_{4\ BW}{}^{0.75}$	2.85a	2.15b	0.162	*
$CH_{4\ DM}$	20.3	21.9	0.57	NS
$CH_{4\ NDF}$	55.7	56.9	1.92	NS
$CH_{4\ dDM}$	29.3	31.2	0.76	NS
$CH_{4\ DNDF}$	113	111	6.9	NS
$CH_{4\ MY}$	12.4	19.6	1.96	t
$CH_{4\ FCM4\%}$	11.2	17.9	2.02	t

(*Continued*)

Table 5. (Continued).

	Genetic Group (GG)			p-Value
Var/Trat	H	F1	SEM	GG
Production				
MY	24.4a	15.6b	1.59	**
FCM4%	27.4a	17.7b	1.85	*
E_{MY}	80.6a	53.2b	5.44	**

Note. GEI = gross energy intake [MJ/d]; GEf = faecal energy [MJ/d]; DEI = digestible energy intake [MJ/d]; GE_{CH4} = energy in methane [MJ/d]; MEI = metabolisable energy intake [MJ/d]; HP_{BW} = heat production per unit of metabolic weight [MJ/d/kg $BW^{0.75}$]; HP = heat production [MJ/d]; Er = retained energy [MJ/d]; DE/GE = digestibility; ME/GE = metabolizability; CH_4 = daily methane emission [g/d]; CH_{4BW} = daily methane emission per BW [g/kg BW]; $CH_{4BW}{}^{0.75}$ = daily methane emission per unit of metabolic weight [g/kg $BW^{0.75}$]; CH_{4DM} = daily methane emission per unit of DMI [g/kg DMI]; CH_{4NDFi} = daily methane emission per unit of NDFi [g/kg NDFi]; CH_{4DDM} = daily methane emission per unit of digestible dry matter [g/kg digestible DM]; CH_{4NDFd} = daily methane emission per unit of digestible NDF [g/kg FDN dig]; $CH_{4\ MY}$ = daily methane emission per unit of milk production [g/kg milk]; MY = daily milk production; FCM4% = milk corrected for 4% of fat; E_{MY} = calculated energy in milk [MJ]; SEM = standard error of the mean; NS = not significant ($p > 0.10$); t = trend ($0.05 < p \leq 0.10$); *= $p \leq 0.05$; **= $p < 0.01$; means followed by different letters in the same line differ by Tukey's test ($p < 0.05$).

4. Discussion

4.1. Pre-calving period

The main effect of genetic group was noticed on BCS. The higher values of BCS in Girolando-F1 compared with Holstein cows were probably due to differences in fat deposition between genetic groups. European-origin cows have higher visceral fat deposition compared to *Bos indicus* and crossbreds, which in turn, have higher subcutaneous deposition (Carvalho et al. 2009). The use of a nutritional plan focused on assuring the maintenance of European-origin cows resulted in greater BCS in crossbred animals, once these animals have intermediate maintenance requirements in comparison to pure parental breeds, especially Holstein (Borges et al. 2015; Carvalho et al. 2018).

The tendency of higher DMI expressed as proportion of BW in Holstein compared with Girolando-F1 cows might be related to metabolism rate, corroborated by the higher heat production. The lower feed intake in *Bos indicus* compared with *Bos taurus* could be attributable to the smaller capacity of the gastrointestinal tract and lower maintenance and production requirements of former (Peron et al. 1993).

The absence of effects of genetic group on apparent total tract digestibility is in agreement with Rennó et al. (2005). The absence of effects of genetic group on methane emissions expressed as daily amount or as a ratio of the BW, $BW^{0.75}$, DMI and NDF was probably due to the similar intake and digestibility of DM and NDF (Castro Bulle et al. 2007).

4.2. Post-calving period

The high genetic merit of *Bos taurus* breeds for milk production seems to be the reason for the main metabolic differences between Holstein and Girolando-F1 cows in the beginning of lactation. Nutrient partitioning of *Bos taurus* breeds prioritises milk production. In *Bos indicus* cows, on the other hand, not only milk production is lower (Angelo et al. 2022), but it is not a priority during nutrient partitioning after calving (Borges et al. 2015). Moreover, *Bos taurus* and *Bos indicus* animals show distinct tissue deposition (Borges et al. 2015). Holstein cows present higher visceral fat deposition compared with *Bos indicus* cows (Carvalho et al. 2009). Visceral fat is metabolised fast and it is one of the reasons why *Bos taurus* animals have greater weight losses and post-calving BCS losses when compared to *Bos indicus* cows (Thompson et al. 1983).

Feed intake is usually related to milk production levels (Xue et al. 2011). The higher milk production of Holstein cows compared with Girolando-F1 cows (Table 5) is related to the higher DMI and $DMI_{BW}{}^{0.75}$, and consequently, the higher NI and only numerically higher GEI observed in Holsteins cows compared with Giroalndo-F1 cows (Tables 4 and 5). Furthermore, the smaller digestive tract in *Bos indicus* compared with *Bos taurus* may also explain the higher intake in Holstein compared with *Bos indicus* (Jorge et al. 1999). Moreover, the lower DMI observed in Girolando-F1 cows might have been related to the higher pre-calving BCS, acknowledged as an important factor depressor of intake by Drackley and Cardoso (2014). Distinct DMI between genetic groups were the main cause of the higher nitrogen intake and the numerically higher energy intake in Holstein compared with Girolando-F1 cows. Enhanced milk yield and DMI increased metabolism rate (National Research Council 2001; Carvalho et al. 2018) and explained the higher heat production in Holstein compared with Girolando-F1 cows.

Methane emissions can be significantly affected by the amount of feed intake, the forage-to-concentrate ratio, the type of carbohydrate, forage preservation, and feeding frequency (Knapp et al. 2014). Higher methane emissions expressed as proportion of BW or $BW^{0.75}$ observed in Holstein compared with Girolando-F1 cows were related to the higher DMI, and consequently higher energy intake on agreement with Johnson and Johnson (1995), as cows were fed the same diet. We attribute the differences in heat production and methane emissions between genetic groups in the present study to the distinct feed intake and milk yield. Our results are confirmed by Kolling et al. (2018), who reported similar milk yield, intake and consequently, methane emissions (expressed as daily amount and per kg of milk) for Holstein and Girolando-F1 cows. Moreover, Silvestre et al. (2022) compared Gyr, Girlando-F1 and Holstein heifers and reported similar maintenance requirements for Holsteins and Girolando-F1. Furthemore, Guadagnin et al. (2023) compared Holstein and Girolando-F1 cows in mid-lactation and reported similar values for milk yield, dry matter intake, heat production (total daily basis) and methane emissions.

On the other hand, the trend of lower methane emission expressed as proportion of milk and fat-corrected milk (FCM) in Holstein compared with Girolando-F1 was related to the higher milk production of the formers. High yielding animals are recognised as more efficient as they have less heat losses and methane emissions per kg of animal product (Hegarty et al. 2007). We evidenced a trend in lower methane emission in Holstein compared with Girolando-F1 when it was expressed per unit of milk production and per kilogram of FCM.

High BCS has negative effects on intake and health (Angelo et al. 2022) and that is well documented in Holstein cows (Drackley and Cardoso 2014), but much less evidenced in *Bos indicus* and crossbreds (Carvalho et al. 2018; Stivanin et al. 2021). The larger subcutaneous adipose tissue deposition in Girolando-F1 compared with Holstein cows induced high BCS scores at the end of gestation/lactation, which can lead to problems in subsequent lactation (Carvalho et al. 2018).

Feeding a nutritional plan elaborated for Holstein and offered to Girolando-F1 cows increased BCS in the latter. Girolando-F1 presented higher BCS than Holstein cows in the *pre* (4.3 × 4.0) and post-calving (3.9 × 3.5) periods, which could negatively affect intake and milk production. However, despite differences in heat production (higher for Holstein) and trends in higher methane emission per kg of milk and per kg of FCM (for Girolando-F1), the remaining variables considered in the present study such as energy and nitrogen retention and apparent digestibility, evidenced similar energy and nitrogen utilisation between genetic groups both in the pre and post-calving. The evaluation of efficiency based on methane emissions depends on the expression units: if methane emissions per unit of intake, per kg of BW or per kg of milk are considered, Girolando-F1 animals had similar, lower or tended to have greater emissions than Holstein cows, respectively. When systemic approaches are used, the emission of methane per kg of animal product is usually considered (Grešáková et al. 2021). Therefore, Holstein cows tended to be more effective than Girolando-F1 cows.

4.3. Heat production (HP) at 24°C versus thermoneutrality

In the present study, we evaluated heat production with cows at pre- and post-calving in respiration chambers kept at 24°C. Under these conditions, postpartum heat production was 0.92 (MJ/d/kg $BW^{0.75}$) for Holstein cows and 0.75 (MJ/d/kg $BW^{0.75}$) for Girolando-F1. We acknowledge that this temperature is above the usual thermoneutral values, reported for Holstein, between −0.5°C and 20°C (West 2003). Nevertheless, Hammond et al. (2016) evaluated Holstein cows in respiration chambers under a temperature range from 12°C to 25°C. Moreover, Machado et al. (2016) used 3/4 Holstein × 1/4 Gyr primiparous crossbreed cows in a similar protocol to ours, except for the temperature inside the respiration chambers held at 22°C. The authors reported values for heat production per unit of metabolic weight in the order of 1.0 MJ, close to those observed in the present study for Holsteins. Therefore, it is possible to infer that the temperature of the respiration chamber used in the present study was not a relevant factor for the higher heat production per kg of metabolic weight of Holstein cows in relation to Girolando-F1. Lee et al. (2022) reported similar daily HP values to ours for lactating Holstein cows using respiratory chambers and temperature within the thermoneutral values.

5. Conclusion

Our hypothesis that genetic group influences the intake, digestibility, energy utilisation, enteric methane emission and nitrogen balance during the transition period was partially accepted, as we evidenced differences between genetic groups in diet intake, heat production, milk yield and methane emissions expressed as proportion of intake, especially during the post-calving period. Holstein cows ingested more feed, yielded more milk, had higher heat production per kg of metabolic weight and tended to present less methane emission per kg of milk compared with Girolando-F1 cows. However, genetic groups present similar values for variables of energy and nitrogen balance, suggesting similar efficiency.

Disclosure statement

All authors declare that there are no present or potential conflicts of interest among the authors and other people or organisations that could inappropriately bias their work.

Funding

This work was supported by the Coordination for the Improvement of Higher Education Personnel (CAPES – Brazil) and National Council for Scientific and Technological Development (CNPq - Brazil).

ORCID

João Pedro Matiello http://orcid.org/0000-0002-3602-3525
Anne Rosi Guadagnin http://orcid.org/0000-0002-1446-5082
Elissa Forgiarini Vizzotto http://orcid.org/0000-0001-6211-7130
Sheila Cristina Bosco Stivanin http://orcid.org/0000-0002-3468-2834
Guilherme Heisler http://orcid.org/0000-0002-8637-4884
Arthur Fernandes Bettencourt http://orcid.org/0000-0002-8332-163X
Thierry Ribeiro Tomich http://orcid.org/0000-0002-8788-5715
Fernanda Samarini Machado http://orcid.org/0000-0002-7380-4961
Luiz Gustavo Ribeiro Pereira http://orcid.org/0000-0001-7166-5817
Vivian Fischer http://orcid.org/0000-0002-7670-7454

References

Angelo IDV, Stivanin SCB, Vizzotto EF, Bettencourt AF, Lopes MG, Correa MN, Pereira LGR, Fischer V. 2022. Feed intake, milk production and metabolism of holstein, gyr and girolando-F1 heifers with high body condition score during the transition period. Res Vet Sci. 152:127–133. doi: 10.1016/j.rvsc.2022.07.025.

Borges ALCC, Teixeira RMA, Silva EA, Fernandes LO, Ruas JRM, Queiroz DS, Lage HF. 2015. Desempenho nutricional de bovinos leiteiros. Inf Agropec. 36:88–99.

Brouwer E 1965. Report of sub-committee on constants and factors. In: Blaxter KL, editor. Proceedings of the Third EAAP Symposium on Energy Metabolism. Troon, Scotland. Vol. 11, p. 441–443.

Carvalho BC, Ruas JRM, Silva JM, Ferreira JJ, Silva MA, Menezes GCC. 2009. Avaliação de diferentes manejos pré-parto sobre o peso e o escore da condição corporal de vacas mestiças F1 Holandês x Zebu. Rev Bras Ciênc Vet. 16:62–67. doi: 10.4322/rbcv.2014.171.

Carvalho PHA, Borges ALCC, Silva RR, Lage HF, Vivenza PAD, Ruas JRM, Facury Filho EJ, Palhano RLA, Gonçalves LC, Borges I, et al. 2018. Energy metabolism and partition of lactating Zebu and crossbred Zebu cows in different planes of nutrition. PLoS ONE. 13:1–10. doi: 10.1371/journal.pone.0202088.

Castro Bulle FCP, Paulino PV, Sanches AC, Sainz RD. 2007. Growth, carcass quality, and protein and energy metabolism in beef cattle with different growth potentials and residual feed intakes. J Anim Sci. 85:928–936. doi: 10.2527/jas.2006-373.

Drackley JK, Cardoso FC. 2014. Prepartum and postpartum nutritional management to optimize fertility in high-yielding dairy cows in confined TMR systems. Anim. 8:5–14. doi: 10.1017/S1751731114000731.

Grešáková Ľ, Holodová M, Szumacher-Strabel M, Huang H, Ślósarz P, Wojtczak J, Sowińska N, Cieślak A. 2021. Mineral status and enteric methane production in dairy cows during different stages of lactation. BMC Vet Res. 17:287. doi: 10.1186/s12917-021-02984-w.

Guadagnin AR, Matiello JP, Ribeiro RS, Pereira LGR, Machado FS, Tomich TR, Campos MM, Heisler G, Fischer V. 2023. Assessment of heat production and methane emission using infrared thermography in lactating Holstein and gyrolando-F1 (½ Holstein ½ Gyr) crossbreed cows. J Thermal Biol. 115:103628. doi: 10.1016/j.jtherbio.2023.103628.

Hegarty RS, Goopy JP, Herd RM, McCorkell B. 2007. Cattle selected for lower residual feed intake have reduced daily methane production. J Anim Sci. 85:1479–1486. doi: 10.2527/jas.2006-236.

Johnson KA, Johnson DE. 1995. Methane emissions from cattle. J Anim Sci. 73:2483–2492. doi: 10.2527/1995.7382483x.

Jorge AM, Fontes CAA, Paulino MF, Gomes P. 1999. Tamanho relativo dos órgãos internos de zebuínos sob alimentação restrita e *ad libitum*. R Bras Zootec. 28:374–380. doi: 10.1590/S1516-35981999000200022.

Hammond KJ, Jones AK, Humphries DJ, Crompton LA, Reynolds CK. 2016. Effects of diet forage source and neutral detergent fiber content on milk production of dairy cattle and methane emissions determined using GreenFeed and respiration chamber techniques. J Dairy Sci. 99:7904–7917. doi: 10.3168/jds.2015-10759.

Knapp JR, Laur GL, Vadas PA, Weiss WP, Tricarico JM. 2014. Invited review: enteric methane in dairy cattle production: quantifying the opportunities and impact of reducing emissions. J Dairy Sci. 97:3231–3261. doi: 10.3168/jds.2013-7234.

Kolling GJ, Stivanin SCB, Gabbi AM, Machado FS, Ferreira AL, Campos MM, Tomich TR, Cunha CS, Dill SW, Pereira LGR, et al. 2018. Performance and methane emissions in dairy cows fed oregano and green tea extracts as feed additives. J Dairy Sci. 101:4221–4234. doi: 10.3168/jds.2017-13841.

Lee C, Beauchemin KA, Dijkstra J, Morris DL, Nichols K, Kononoff PJ, Vyas D. 2022. Estimates of daily oxygen consumption, carbon dioxide and methane emissions, and heat production for beef and dairy cattle using spot gas sampling. J Dairy Sci. 105:9623–9638. doi: 10.3168/jds.2022-22213.

Machado FS, Tomich TR, Ferreira AL, Cavalcanti LFL, Campos MM, Paiva CAV, Ribas MN, Pereira LGR. 2016. Technical note: a facility for respiration measurements in cattle. J Dairy Sci. 99:4899–4906. doi: 10.3168/jds.2015-10298.

Madalena FE, MGCD P, Gibson J. 2012. Dairy cattle genetics and its applications in Brazil. Livest Res Rural Dev. 24:97.

McManus C, Paludo GR, Louvandini H, Gugel R, Sasaki LCB, Paiva SR. 2009. Heat tolerance in Brazilian sheep: physiological and blood parameters. Trop Anim Health Prod. 41:95–101. doi: 10.1007/s11250-008-9162-1.

Mellado M, Coronel F, Estrada A, Ríos FG. 2011. Lactation performance of holstein and holstein x gyr catltle under intersive condition in a subtropical environment. Trop Subtrop Agroecosyst. 14:927–931.

National Research Council. 2001. Nutrient requirements of dairy cattle. 7th rev. ed. Washington, DC: National Academies Press.

Peron AJ, Fontes CAA, Lana RP. 1993. Tamanho de órgãos internos e distribuição da gordura corporal em novilhos de cinco composição racial submetidos a alimentação restrita e *ad libitum*. Rev Bras Zoot. 22:813–819.

Rennó LN, Valadares Filho SC, Valadares RFD, Cecon PR, Backes AA, Rennó FP, Alves DD, Silva PA. 2005. Níveis de uréia na ração de novilhos de quatro grupos genéticos: Consumo e digestibilidades totais. R Bras Zootec. 34:1775–1785. doi: 10.1590/S1516-35982005000500039.

Sguizzato ALL, Marcondes MI, Dijkstra J, Valadares Filho SC, Campos MM, Machado FS, Silva BC, Rotta PP. 2020. Energy requirements for pregnant dairy cows. PLoS ONE. 15:e0235619. doi: 10.1371/journal.pone.0235619.

Silvestre T, Ferreira AL, Machado FS, Campos MM, Tomich TR, Pereira LGR, Rodrigues PHM, Marcondes MI. 2022. Energy requirements of Holstein, Gyr, and Holstein × Gyr crossbred heifers using the respirometry technique. Front Anim Sci. 3:919515. doi: 10.3389/fanim.2022.919515.

Stivanin SCB, Vizzotto EF, Matiello JP, Machado FS, Campos MM, Tomich TR, Pereira LGR, Fischer V. 2021. Behavior, feed intake and health status in holstein, gyr and girolando-F1 cows during the transition period. Appl Anim Behav Sci. 242:105403. doi: 10.1016/j.applanim.2021.105403.

Thompson WR, Meiske JC, Goodrich RD, Rust JR, Byers FM. 1983. Influence of body composition on energy requirements of beef cows during winter. J Anim Sci. 56:1241–1252. doi: 10.2527/jas1983.5651241x.

Van Soest PJ, Robertson JB, Lewis BA. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polyssacarides in relation to animal nutrition. J Dairy Sci. 74:3583–3597. doi: 10.3168/jds.S0022-0302(91)78551-2.

Vieira MT, Daltro DS, Cobuci JA. 2022. Breed and heterosis effects on reproduction and production traits of Girolando cows. Braz J Anim Sci. 51:1516–3598. doi: 10.37496/rbz5120200266.

Villanueva C, Ibrahim M, Castillo C. 2023. Enteric methane emissions in dairy cows with different genetic groups in the humid tropics of Costa Rica. Animals. 13:730. doi: 10.3390/ani13040730.

Vizzotto EF, Stivanin SCB, Matiello JP, Machado FS, Campos MM, Tomich TR, Pereira LGR, Stone V, Klein CP, Matté C, et al. 2021. Feed intake, performance and redox status in Holstein and Girolando F1 heifers presenting high body condition score during the transition period. Livest Sci. 54:104732. doi: 10.1016/j.livsci.2021.104732.

West JW. 2003. Effects of heat-stress on production in dairy cattle. J Dairy Sci. 86:2131–2144. doi: 10.3168/jds.S0022-0302(03)73803-X.

Xue B, Yan T, Ferris CF, Mayne CS. 2011. Milk production and energy efficiency of Holstein and Jersey-Holstein crossbred dairy cows offered diets containing grass silage. J Dairy Sci. 94:1455–1464. doi: 10.3168/jds.2010-3663.