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Ruminal methane emission and lactational performance of cows fed rapeseed cake and oats on a grass silage–based diet

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ABSTRACT

The objective of this experiment was to investigate the effect of lipid from rapeseed cake and oats on ruminal CH_4 emission and lactational performance of dairy cows. Twelve lactating Nordic Red cows, of which 4 were primiparous, and averaging (±SD) 48 ± 22.9 DIM, 37.8 ± 7.14 kg/d milk yield were enrolled in a switch-back design experiment with 3 periods of 4 wk each. The cows were assigned into 6 pairs based on parity, DIM, milk yield, and BW at the beginning of the experiment. The experimental treatments were (1) rapeseed cake and oats (RSC+O), and (2) rapeseed meal and barley (RSM+B) as the concentrate feeds. Cows in each pair were randomly assigned to 1 of the 2 groups, which received the treatments in 2 different sequences (i.e., group 1 received RSC+O in period 1 and 3, and RSM+B in period 2, whereas group 2 was fed RSM+B in period 1 and 3, and RSC+O in period 2). The diets consisted of a partially mixed ration with grass silage mixed with either oats or barley, according to the treatment sequence, and the rapeseed cake or meal being mixed into a pellet with either oats or barley according to the treatments, and a mineral mix. The pellet was delivered at a fixed amount (i.e., 6 kg/d for multiparous and 5 kg/d for the primiparous cows) from the milking robot. The actual forage to concentrate ratios for RSC+O and RSM+B were 51:49 and 52:48, respectively, with NDF concentrations of 41.5% and 36.0% and CP concentrations of 17.0% and 16.7% of diet DM. Dry matter intake, milk yield, and gas exchange (with a GreenFeed system attached to the milking robot) were recorded daily, and milk composition and spot fecal samples were collected during the last week of each period. Based on feed analysis, and DMI of the cows during the experiment, the total fat content of the experimental diets was 4.1% and 2.7% of DM for RSC+O and RSM+B diets, respectively. Dry matter intake was 1.6 kg/d lower, and milk yield tended to be 1.0 kg/d greater for RSC+O versus RSM+B. There were no differences in ECM yield and milk composition between the treatments, whereas milk ME efficiency was greater for cows fed RSC+O than RSM+B. Methane yield (g/kg DMI) did not differ between treatments, but CH_4 production (g/d) was 9.4% and CH_4 intensity as g/kg ECM was 11.7% lower for RSC+O versus RSM+B. The lower CH_4 production was likely caused by the lower DMI and fiber digestibility, observed with the RSC+O diet. In addition, the greater lipid intake also contributed to lower rate of fermentation and subsequent decrease in CH_4 production. Overall, feeding rapeseed cake with oats in a grass silage–based diet increased feed efficiency while decreasing CH_4 emission intensity in lactating cows. This provides a practical way of mitigating ruminal CH_4 emission from dairy operations while maintaining milk production with commonly used feedstuffs in Nordic conditions.

Key words: ruminal methane emission, rapeseed cake, oats, dairy cow

INTRODUCTION

Ruminants are an essential part of food production systems as users of resources not directly available for food crop production, especially so in increasingly challenging production conditions due to the on-going climate change. However, they also contribute to majority of the livestock enteric CH_4 emission (FAO, 2019), an inevitable end product of digestion of cellulose by rumen microbes. To decrease the contribution of enteric CH_4 from ruminants, several different mitigation strategies have been tested and identified. The most important considerations of different strategies include cost efficiency for the farmer, no negative effects on productivity, animal health, or environment as well as easiness of implementation (Hristov et al., 2013). In a recent comprehensive meta-analysis, Arndt et al. (2022) identified several effective CH_4 mitigation strategies including product-based

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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-24. Nonstandard abbreviations are available in the Notes.

strategies (increasing feeding level, decreasing grass maturity, and decreasing dietary forage-to-concentrate ratio) and absolute reduction strategies (CH_4 inhibitors, tanniferous forages, electron sinks, oils, and fats, as well as oilseeds).

Of these strategies, lipids have been extensively studied and shown a consistent reduction in enteric CH_4 emission, yield, and intensity (Arndt et al., 2022) but their practical implementation and feasibility is dependent on the effects of dietary lipid on feed intake, productivity, milk fat content as well as feed costs (Grainger and Beauchemin, 2011; Hristov et al., 2013). Meta-analyses have reported a decrease in CH_4 production by around 3.5% to 3.8% for every percentage-unit increase in dietary lipid content (Moate et al., 2011; Patra, 2013).

A feasible and practical way to supply lipids is in the form of byproducts from agricultural and food processing industries, such as whole cottonseed, brewers grains, cold pressed canola (rapeseed), and hominy meal. These are feeds that are currently fed as a part of lactating dairy cow rations, without negative effects on DMI, digestibility, rumen fermentation, or productivity (Grainger and Beauchemin, 2011; Hristov et al., 2022). Brask et al. (2013a) reported no difference in production parameters or digestibility of nutrients between a control diet and different forms of rapeseed lipid supplementation including rapeseed cake (**RSC**), whole cracked rapeseed, and rapeseed oil. However, CH_4 production and intensity were decreased by 7% to 11% with rapeseed lipid supplementation, regardless of source (Brask et al., 2013a). In a recent study (Bayat et al., 2022), cows fed RSC in a grass silage–based diet had a greater milk yield (**MY**) and ECM yield compared with rapeseed meal (**RSM**), whereas both CH_4 yield (g/kg DMI) and intensity (g/kg ECM) were decreased by 7% and 12%, respectively.

Another way to increase the lipid content of the diet in grass silage–based diets is to replace barley, which is commonly included in dairy cow diets in Nordic dairy systems as an energy source, with oats (Fant et al., 2020, 2021). The CH_4 mitigation effect of oats has been attributed to the lower digestibility and greater lipid content of oats (Fant et al., 2020; Ramin et al., 2021), and the greater ECM yield, and thereby lower CH_4 intensity of cows receiving oats compared with cows fed barley (Fant et al., 2021). An in vitro experiment comparing CH_4 from barley and oats predicted an 8.9% decrease in CH_4 production in vivo (Fant et al., 2020). Further, 2 recent in vivo experiments reported 5.7% (Fant et al., 2021) and 4.8% (Ramin et al., 2021) decreases in CH_4 intensity when barley was replaced with oats.

Combining 2 feeds, such as RSC and oats in the Nordic context, that are affordable and readily available to farmers with positive effects on production, and with a CH_4 mitigating potential, offers a practical way to improve the environmental sustainability of dairy farms. Therefore, the objective of this experiment was to test the effect of isonitrogenous replacement of RSM and barley with RSC and oats (i.e., increasing lipid and fiber supplies) on enteric CH_4 emission and lactational performance of dairy cows. The hypothesis was that CH_4 production and intensity of cows fed RSC and oats would be lower compared with cows receiving RSM and barley.

MATERIALS AND METHODS

The experiment was conducted at the University of Helsinki research farm in Helsinki, Finland. Experimental procedures were approved by the Viikki Campus Research Ethics Committee of the University of Helsinki in accordance with the guidelines established by the European Union Directive 2010/63/EU and the current Finnish legislation on animal experimentation (Act on the Protection of Animals Used for Scientific or Educational Purposes 497/2013).

Animals, Housing, and Experimental Design

A total of 12 Nordic Red cows, of which 4 primiparous and 8 multiparous, averaging (±SD) 48 ± 22.9 DIM, 37.8 ± 7.14 kg/d MY, and 648 ± 59.0 kg BW were enrolled in the study. The cows were assigned into 6 pairs based on parity, DIM, MY, and BW at the beginning of the experiment. One cow from each pair was randomly assigned into 1 of the 2 treatment sequences. The study was designed as a switch-back experiment with 3 periods of 4 wk each. Sample collections were carried out during wk 4 of each experimental period. The cows were housed in a freestall section of the barn equipped with a roughage intake control system (Insentec BV, Markenesse, the Netherlands), and free access to drinking water. The cows had free access to an automatic milking robot (Lely Astronaut A3, Lely International, Maassluis, the Netherlands).

Experimental Diets and Treatments

The chemical composition of the experimental feeds is presented in Table 1. Both experimental diets included a first-cut grass silage (mixed timothy [*Phleum pratense*] and meadow fescue [*Festuca pratensis*] sward) harvested on June 9, 2021, at the Viikki research farm in Helsinki, Finland (60° N, 25° E) into round bales. The bales were preserved with formic acid-based additive (AIV2 Plus Na, Taminco Finland Ltd., Oulu, Finland) targeted at 6 L/1,000 kg. During preparation of partial mixed ration (**PMR**) the silage was further chopped to 30 to 40 mm length in a feed mixer (CutMix, Pellon Group, Ylihärmä, Finland). The PMR included the grass silage and a ce-

Table 1. Chemical composition (SD in parentheses) of the experimental feeds[1]

Item	Grass silage[2]	Oats	Barley	RSC+O robot feed[3]	RSM+B robot feed[4]
DM, %	23.4 (1.41)	85.8 (1.02)	86.8 (0.53)	87.1 (0.15)	86.9 (0.69)
Chemical composition, % of DM					
Ash	9.11 (0.224)	3.63 (0.167)	2.51 (0.138)	10.7 (0.126)	10.7 (0.247)
Acid-insoluble ash	1.78 (0.081)	1.58 (0.125)	0.577 (0.1503)	0.420 (0.0084)	0.273 (0.013)
NDF	53.7 (0.88)	32.1 (0.33)	15.3 (2.00)	26.4 (0.67)	19.6 (0.16)
Starch	0.226	32.4 (1.67)	53.9 (0.912)	12.0 (0.14)	18.0 (1.17)
Total fat	2.63 (0.195)	4.58 (0.214)	2.56 (0.066)	7.25 (0.100)	2.96 (0.040)
OM	90.9 (0.22)	96.4 (0.29)	97.5 (0.14)	89.3 (0.13)	89.3 (0.25)
CP	15.6 (1.54)	15.3 (1.02)	12.9 (0.45)	26.3 (0.29)	25.8 (0.48)
MP[5]	8.29	8.90	9.40	13.6	13.6
ME,[5] MJ/DM	10.9	11.5	12.5	11.5	11.4

[1]Chemical analyses were performed on 3 samples (1 composite sample per period) of each feed ingredient. For starch analysis of grass silage, one composite sample for the entire experiment was used.

[2]Fermentation quality of grass silage (% in DM): 5.57% lactic acid, 0.556% ethanol, 1.04% acetic acid, 6.77% water soluble carbohydrates, 6.42% NH_3-N of total N, pH 4.06. D-value (percentage of digestible OM in forage DM): 68.1.

[3]Rapeseed cake and oats pellet (Lantmännen Agro, Vantaa, Finland) was 88% DM and contained (as-is basis) 60% rapeseed cake, 30.3% oats, 5.0% molassed sugar beet pulp, and 4.7% mineral mix.

[4]Rapeseed meal and barley pellet (Lantmännen Agro, Vantaa, Finland) was 88% DM and contained (as-is basis) 56.9% rapeseed meal, 33.4% barley, 5.0% molassed sugar beet pulp, and 4.7% mineral mix.

[5]Based on analyzed chemical composition and Finnish feed evaluation system (Luke, 2023).

real concentrate (oats or barley) grown on the farm and was mixed in a feeding wagon (TMR-SUK M2, Pellon Group). The PMR was delivered 3 times/d at 0800, 1200 and 1800 h and was offered ad libitum. In addition, 2 isonitrogenous pelletized experimental robot feeds (Lantmännen Agro, Vantaa, Finland) including RSC and oats or RSM and barley, as well as molassed sugar beet pulp and vitamins and minerals, were offered in the milking robot at a fixed amount (i.e., 6 kg/d for multiparous and 5 kg/d for primiparous cows). The robot feed was fed out at a rate of 400 g/min and the daily fed out amount was assumed to be consumed entirely by the cows and used for calculation of total DMI (PMR + robot feed intake). The recomposited experimental diets, based on the chemical analysis of feeds and intake of cows during the experiment, are presented in Table 2. The experimental treatment diets were (1) PMR with oats and the pelleted robot feed containing RSC and oats (**RSC+O**) and (2) PMR with barley, and RSM and barley as the pelleted robot feed (**RSM+B**), respectively. According to the switchback design sequence 1 received RSC+O in period 1 and 3, and RSM+B in period 2, whereas sequence 2 was fed RSM+B in period 1 and 3, and RSC+O in period 2. The forage-to-concentrate ratio of the whole feeding regimen, including PMR and pelleted robot feed was on DM-basis 51:49 and 52:48, for RSC+O and RSM+B respectively.

Sample Collections and Analysis

Feed Sampling and Analysis. Representative samples of the experimental feeds were taken 3 times during wk 4 of each period. All feed samples were composited by period and dried at 50°C for 48 h for subsequent feed analysis. Subsamples were dried at 103°C for 24 h, and DM was determined and used for calculation of DMI. Further, separate samples of fresh silage were stored at –20°C for analysis of fermentation quality.

Water-soluble carbohydrates (Somogyi, 1945; Salo, 1965), and NH_3-N nitrogen (McCullough, 1967) concentrations were analyzed using colorimetric methods using a spectrophotometer (Perkin-Elmer 55B, Shi-

Table 2. Ingredient and chemical composition of experimental diets

Item	Treatment[1] RSC+O	RSM+B
Feed ingredients, % of DM[2]		
Grass silage	51.2	51.8
Oats	28.5	—
Barley	—	29.3
RSC+O, robot feed	20.3	—
RSM+B, robot feed	—	18.9
Chemical composition, % of DM		
OM	92.1	92.5
CP	17.0	16.7
NDF	41.5	36.0
Starch	12.1	19.3
Total fat	4.10	2.68
Ash	7.84	7.48
Acid-insoluble ash	1.43	1.15
MP[3]	9.69	9.63
ME,[3] MJ/ kg DM	11.2	11.5

[1]Experimental treatments were rapeseed cake and oats (RSC+O), or rapeseed meal and barley (RSM+B) as the concentrate feeds. The treatments were fed as a pelleted robot feed, and a PMR with grass silage and oats or barley.

[2]Based on the actual intake of PMR (grass silage, oats, and barley), and the individual fed out amount of robot feed during the experiment.

[3]Based on chemical analysis and Finnish feed evaluation system (Luke, 2023) for rumen degradable protein fractions and energy content.

madzu UV-VIS mini 1240; Shimadzu Europa GmbH), and ethanol concentration by an enzymatic kit (cat. no. 176290, Boehringer Mannheim, Mannheim, Germany). Volatile fatty acid and lactic acid concentrations were determined by ultra-performance liquid chromatography (Waters Acquity UPLC, Waters, Milford, MA). The dried feed samples were ground through a 1-mm screen and analyzed for DM, OM, NDF (reported in ash-free basis), CP, and acid insoluble ash (**AIA**). Neutral detergent fiber content was analyzed in the presence of sodium sulfite according to Van Soest et al. (1991) using a FiberTherm FT12 analyzer (Gerhardt, Königswinter, Germany), CP content was determined with the Kjeldahl method (AOAC International, 1995), AIA by acid hydrolysis (Van Keulen and Young, 1977), starch concentration by the amyloglucosidase and α-amylase method, after ethanol washing with K-TSTA kit (Megazyme, Co. Wicklow, Ireland), and total fat with petroleum ether extraction and hydrolysis with HCl (SoxCap 2047 Hydrolysis Unit, Foss Soxtec 8000; Foss Analytical, Hillerød, Denmark). The DM content of silages was corrected for the loss of volatile compounds (lactic acid, VFA, NH_3-N, and ethanol) according to Huida et al. (1986).

Fecal Samples. Spot fecal samples were collected from the rectum on wk 4 of each experimental period for 5 d at 0900 h. A total of 1 L (~750 g) of fecal sample was collected at each sampling and stored frozen at –20°C. The fecal samples were thawed and composited by cow and period. The composite samples were dried at 70°C for 48 h, ground through 1-mm sieve and analyzed for chemical composition as described above for feed samples. A fresh subsample was used for fecal N determination. The AIA concentration of the feeds and fecal samples was used as an internal marker for estimation of apparent total-tract digestibility of nutrients (Van Keulen and Young, 1977).

Milk Yield and Composition. Milk yield from each milking was recorded throughout the experiment, and the daily MY was calculated as the sum of MY from each milking over the last 7 d of each period and divided by 7. Milk samples were collected during wk 4 of each period over a 48-h period with a minimum of 4 samples per cow and period (averaging 5.28 ± 1.059) using automated sampling device (Lely Shuttle A3). All samples collected over the 48-h period were analyzed. Samples were preserved with 2-bromo-2-nitropropane-1,3-diol (Bronopol; Valio Ltd., Helsinki, Finland) and sent for analysis to a commercial laboratory (Valio Ltd., Seinäjoki, Finland), where they were analyzed for milk fat, CP, lactose, and urea concentrations (MilkoScan FT+; Foss Electric A/S, Hillerod, Denmark). Further, the BW was measured in the milking robot at each milking and BCS was determined by 3 independent observers at the beginning of the experiment and at the end of each period based on the 5-point scale by Edmonson et al. (1989).

Gas Exchange of the Rumen and Lungs. The gas exchange (i.e., gases emitted from the rumen or lungs [CH_4, CO_2, and H_2] or gases that were absorbed via lungs [O_2]) measurements were recorded during each milking with a GreenFeed unit (C-Lock Inc., Rapid City, SD) that was incorporated into the milking robot as described in detail by Huhtanen et al. (2015). The experimental robot feeds functioned as the bait feed. The average number of successful visits (at least 2 min of uninterrupted measurement) per cow over the 7-d sampling period was 15.1 ± 4.04 and 16.3 ± 3.88 for cows on RSC+O and RSM+B treatments, respectively. Only cows with a minimum of 10 successful visits within the measurement week were included in the statistical analysis. Thereby, 1 cow with less than 10 gas exchange measurements for each of the 3 periods was excluded. The GreenFeed unit was calibrated before each sampling week following the manufacturer's recommendations (http://greenfeed.c-lockinc.com). Methane yield (i.e., g/kg DMI) and intensity (i.e., g/kg MY or ECM) were calculated using the 7-d average of DMI and MY, and ECM yield during the sampling week.

Calculations and Statistical Analysis

Milk composition was calculated as weighted averages based on the milk production at each milking corresponding to the sample. The calculated milk composition was used in statistical analysis and for calculation of milk component yields and ECM. The ECM yield was calculated according Sjaunja et al. (1991), and MUN concentration as milk urea concentration multiplied by 0.47. The ME content of the grass silage was calculated as 0.16 × D-value. The D-value (% of DM) is the in vitro digestible OM in DM, determined according to Nousiainen et al. (2003). The ME (both uncorrected and corrected) and MP supplies and balances were calculated according to Finnish feed evaluation system and as described in detail in Luke (2023) and based on production, intake, and BW of cows during the experiment. The corrected ME supply included corrections for dietary energy and CP content, as well as DMI during the experiment. Metabolizable energy and MP requirements include estimations of maintenance and production requirements (Luke, 2023). Efficiency of ME utilization for milk production was calculated without liveweight change as [3.14 MJ × ECM yield (kg/d)] ÷ [corrected ME intake (MJ/d) − ME requirements for maintenance (MJ/d)].

All data were averaged over the last 7 d of each experimental period and analyzed using PROC MIXED of SAS (version 9.4; SAS Institute Inc., Cary, NC). The model included the fixed effect of treatment, period, pair, and treatment sequence (group 1 or group 2), and the random effect of cow within sequence. The normality of the model residuals was tested by the Shapiro-Wilk test and heterogeneity was explored visually. All data are presented as least squares means. Statistical differences were considered significant at $P \leq 0.05$ and a trend at $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Feed Composition

The grass silage used in the current experiment was within a normal range with a good digestibility (D-value of 68% of DM) and moderate CP content of 15.6% of DM (Table 1). Silage fermentation qualities were good as indicated by low pH value, as well as low contents of lactic and acetic acids. Of the experimental feeds, oats and RSC+O pellet had a greater NDF and total fat contents, but lower starch content, compared with barley and RSM+B pellet, respectively. The CP content of oats was 2.4 percentage units greater than barley and was similar between the robot pellet feeds. Reflecting the differences in the experimental feeds (i.e., oats vs. barley and RSC+O pellet vs. RSM+B pellet), the experimental diets differed mostly in NDF, starch, and total fat contents, and as a result the RSC+O diet had a slightly lower energy content compared with RSM+B diet (Table 2).

Supplementation of lipids through feed ingredients, such as oats or RSC, is often more economically feasible than oils, and thereby a more attractive strategy for practical application. Previous studies have compared RSC with RSM (e.g., Brask et al., 2013a,b; Bayat et al., 2022), or replacement of barley with oats (e.g., Vanhatalo et al., 2006; Fant et al., 2021; Ramin et al., 2021), whereas in the current study the aim was to investigate the combined effect of these 2 lipid sources (i.e., RSC and oats). Comparisons to previous literature are mostly made on the basis of provision of lipids from rapeseed or oats, and fiber from oats, as detailed below.

Feed and Nutrient Intake and Apparent Total-Tract Digestibility

The DMI was 1.6 kg/d lower ($P = 0.01$; Table 3) for cows receiving RSC+O versus RSM+B, which resulted from a lower ($P = 0.005$) PMR intake of RSC+O-fed cows. Similarly, OM, CP, and starch intakes were lower ($P \leq 0.02$), whereas intakes of total fat and NDF were greater ($P \leq 0.01$) for RSC+O compared with RSM+B. Digestibilities of all nutrients, except for CP and total fat, were lower ($P < 0.001$) for cows fed RSC+O than cows fed RSM+B. Further, ME and MP supplies were lower ($P \leq 0.02$) for RSC+O versus RSM+B.

Despite the lower DMI, cows on RSC+O diet had a 0.31 kg/d greater total fat intake compared with cows on the RSM+B diet, resulting from the greater total fat content of the diet RSC + O (4.1% vs. 2.7% of DM, respectively). In general, supplementary lipids decrease DMI through decreased fiber digestibility, as well as through gut peptide signaling and fatty acid oxidation in the liver, which in turn alter signals of satiety to the brain (Allen, 2000). The observed decline in DMI in the current study, is in line with meta-analysis by Knapp et al. (2014) on incorporation of lipids in dairy cow diets, where increasing ether extract (**EE**) from oilseeds in feed rations by 1 percentage unit reduced DMI by 0.9 ± 0.52 kg. In another study, mechanically extracted canola meal fed in a corn silage–based diet (5.7% EE of DM) led to a 1.6 kg/d reduction in DMI compared with a diet with solvent-extracted canola meal with a lower EE content (3.9% of DM; Hristov et al., 2011). Bayat et al. (2022), however, did not observe any difference in DMI when RSM was replaced with RSC with a dietary lipid content of 3.5% and 5.0% of DM, respectively, in a grass silage–based diet. Further, DMI was not affected when replacing barley (3.4% crude fat of DM) with hulled or dehulled oats, or their mixture (dietary crude fat contents of 4.3%, 4.8%, and 4.6% of DM, respectively; Fant et al., 2021), or when gradually replacing barley with oats with an increase in dietary fat content from 2.7% to 3.6% of DM (Ramin et al., 2021).

Lipids can reduce total-tract digestibility of fiber (Beauchemin et al., 2008, 2009; Knapp et al., 2014), which was also observed in the current experiment with OM and NDF digestibilities decreased by 8.3% and 10.2%, respectively, for cows receiving RSC+O diets. A recent study in which diets were formulated to be isonitrogenous, and only differ in EE content (5.0% vs. 3.5% of DM) by inclusion of RSC versus RSM, nutrient digestibility was similar between the diets (Bayat et al., 2022), which agrees with results reported by Brask et al. (2013a). As the effect of lipids on OM and NDF digestibility have been variable across studies (e.g., Bayat et al., 2022; Halmemies-Beauchet-Filleau et al., 2023), the lower OM digestibility of RSC+O diet in the current study can be partly explained by lower OM digestibility of oats compared with barley. Indeed, Ramin et al. (2021) observed a 3.8% and 10% reduction in apparent digestibility of OM and NDF, respectively, when replacing barley with oats in a grass silage–based TMR with canola meal as the protein supplement. Similarly, Vanhatalo et al. (2006) observed a 2.8% and 6.5% lower OM and NDF digestibility, respectively, for cows receiving oats versus barley as the grain in grass silage–based diets. In both studies, the decreased OM and NDF digestibilities were attributed to the greater fiber content, specifically greater iNDF content, of oats (Vanhatalo et al., 2006; Ramin et al., 2021). In light of previous studies, the lower digestibility observed for cows fed the RSC+O diets can be mostly attributed to the combined effect of the greater

Table 3. Intake and apparent total-tract digestibility of nutrients in lactating dairy cows fed rapeseed cake and oats or rapeseed meal and barley as concentrate feeds

	Treatment[1]			
Item	RSC+O	RSM+B	SEM[2]	*P*-value
Nutrient intake, kg/d				
Total DMI[3]	23.9	25.6	0.54	0.007
PMR	19.0	20.8	0.57	0.005
Robot feed	4.84	4.83	0.031	0.82
OM	22.1	23.6	0.50	0.009
CP	4.07	4.27	0.078	0.02
Total fat	0.987	0.680	0.018	<0.001
NDF	9.94	9.23	0.251	0.01
Starch	2.90	4.89	0.078	<0.001
Apparent total-tract digestibility, %				
DM	63.2	69.0	0.43	<0.001
OM	64.9	70.8	0.44	<0.001
CP	66.8	65.9	0.65	0.17
Total fat	72.3	66.2	0.96	<0.001
NDF	45.8	51.0	0.78	<0.001
Starch	98.9	99.3	0.06	<0.001
Energy and protein supply[4]				
Corrected ME supply, MJ/d	252	271	5.15	0.002
Uncorrected ME supply, MJ/d	269	293	6.04	0.002
MP supply, g/d	2,321	2,454	46.1	0.02

[1]Experimental treatments were rapeseed cake and oats (RSC+O), or rapeseed meal and barley (RSM+B) as the concentrate feeds. The treatments were fed as a pelleted robot feed, and a PMR with grass silage and oats or barley.

[2]Largest SEM published in table; n = 36 (n represent number of observations used in the statistical analysis). Data are presented as LSM.

[3]Includes the PMR intake (offered ad libitum) and a maximum fixed amount of robot feed provided from the milking robot; the intake from robot feed is the amount fed out per day (for details see Materials and Methods).

[4]Calculated according to Finnish feed evaluation system (Luke, 2023). The corrected ME supply included corrections for dietary nutrient content.

fiber supply from oats, and greater supply of lipids from both RSC and oats.

The observed greater fat digestibility for the RSC+O diet was expected, due the greater dietary supply of lipids from this diet combined with a relatively high digestibility of lipids in the small intestine (Boerman et al., 2015). Further, our data align well with the reported EE digestibility by Bayat et al. (2022) of 73% and 65% for a grass silage–based diet including RSC or RSM, respectively. Albeit the marginally greater starch digestibility for cows fed RSM+B, starch was almost completely digested regardless of diet (99.3% vs. 98.9%). Cows receiving RSM+B had a greater starch intake compared with RSC+O as can be expected from the greater starch content of barley.

Lactational Performance

Milk yield tended to be ($P = 0.10$; Table 4) 1.1 kg/d greater and feed efficiency (kg ECM/kg DMI) was greater ($P = 0.05$) for RSC+O than for RSM+B. Further, ME utilization for milk production was also greater ($P = 0.009$) for cows fed RSC+O versus RSM+B. There were no differences in ECM yield, or milk component concentrations or yields, except for a tendency ($P = 0.08$) for a greater milk lactose yield for RSC+O compared with RSM+B. Due to lower DMI and numerically greater ECM yield, the cows receiving the RSC+O diet were in slightly negative corrected ME balance, in contrast to positive BW and BCS changes in both treatment groups. Metabolizable energy balance calculated without correction for diet composition and intake level was positive also for RSC+O. Nevertheless, both calculated ME balances indicated lower energy status of cows fed with RSC+O. This is in line with lower BCS ($P = 0.02$) and tendency for lower BCS change ($P = 0.10$) for cows receiving RSC+O versus RSM+B. The milking frequency (number of milkings/d) was not different between the dietary treatments.

Despite the lower DMI and energy intakes, cows receiving RSC+O produced more milk, and thereby had a greater feed efficiency and ME utilization for milk production than cows fed RSM+B. However, ECM or milk component yields were not affected. The greater MY for cows receiving oats versus barley is in line with Vanhatalo et al. (2006) and Fant et al. (2021), but McKay et al. (2019) and Ramin et al. (2021) reported no difference in MY between cows receiving oats or barley. The 1.4 kg/d greater MY in Fant et al. (2021) was attributed to both altered glucose partitioning and increased lipids

Table 4. Lactational performance of lactating cows fed rapeseed cake and oats or rapeseed meal and barley as concentrate feeds

Item	Treatment[1]			
	RSC+O	RSM+B	SEM[2]	*P*-value
Milk yield, kg/d	34.7	33.6	0.92	0.10
ECM yield,[3] kg/d	38.3	37.7	0.98	0.53
ECM feed efficiency,[4] kg/kg	1.60	1.48	0.058	0.05
ME utilization for milk production,[5] MJ/MJ	0.668	0.605	0.0187	0.009
Milk protein, %	3.86	3.95	0.05	0.27
Yield, kg/d	1.33	1.33	0.029	0.91
Milk fat, %	4.64	4.71	0.10	0.59
Yield, kg/d	1.61	1.58	0.051	0.67
Milk lactose, %	4.49	4.49	0.016	0.85
Yield, kg/d	1.56	1.51	0.041	0.08
MUN,[6] mg/dL	16.3	15.1	0.53	0.11
Milk N efficiency, %	0.323	0.305	0.0097	0.88
Corrected ME balance,[7] MJ/d	−12.4	10.1	7.64	0.004
Uncorrected ME balance,[7] MJ/d	5.03	31.7	8.32	0.003
MP balance,[7] g/d	−117	−4.23	56.5	0.11
BW, kg	660	661	10.7	0.67
BW change,[8] kg/d	0.035	0.072	0.0857	0.77
BCS[9]	3.03	3.09	0.095	0.02
BCS change[9]	0.013	0.099	0.034	0.10
Milking frequency, milkings/d	2.72	2.77	0.106	0.31

[1]Experimental treatments were rapeseed cake and oats (RSC+O), or rapeseed meal and barley (RSM+B) as the concentrate feeds. The treatments were fed as a pelleted robot feed, and a PMR with grass silage and oats or barley.

[2]Largest SEM published in table; n = 36 (n represent number of observations used in the statistical analysis). Data are presented as LSM.

[3]Calculated according to Sjaunja et al. (1991).

[4]Calculated as ECM (kg/d) ÷ DMI, kg/d.

[5]ME utilization for milk production was calculated as [3.14 MJ × ECM yield (kg/d)] ÷ [corrected ME intake (MJ/d) − ME requirements for maintenance (MJ/d)], (Luke, 2023).

[6]Calculated as milk urea concentration × 0.47.

[7]Calculated according to Finnish feed evaluation system (Luke 2023) and based on production, intake, and BW change of cows during the experiment. The corrected ME supply included corrections for dietary nutrient content.

[8]BW change (kg/d) was BW change (kg) within a period ÷ 28 d.

[9]Based on the 5-point scale by Edmonson et al. (1989). Body condition score change was calculated as the difference in BCS between experimental periods.

supply from oats, the latter leading to more glucose being available for lactose synthesis instead of de novo fatty acid synthesis. Indeed, Ekern et al. (2003) reported an increased MY both when barley-based concentrate was replaced with an oat-based concentrate, but also when a high-fat oat variety was compared with a low-fat variety. Further, Ramin et al. (2021) suggested that an increased or maintained MY in cows fed oats could result from less energy being partitioned toward body fat reserves. In the current study, both oats and RSC provided additional lipids from the diet (total fat content of 4.1% vs. 2.7% of DM for RSC+O vs. RSM+B), which contributed to the observed greater MY. Interestingly, Brask et al. (2013a) did not observe any difference in production parameters of dairy cows fed RSC versus RSM, whereas Bayat et al. (2022) reported a notable increase of 4 kg/d in MY and 2.6 kg/d increase in ECM yield in cows fed RSC versus RSM. They attributed this effect to the greater energy content in RSC, as there was no difference in DMI, but a greater lactose concentration and yield, which in turn drives milk volume (Kronfeld, 1982). Further, similar to both the current study and Bayat et al. (2022), Hristov et al. (2011) reported a greater feed efficiency in cows supplemented with a mechanically extracted canola meal compared with a solvent-extracted canola meal with a lower fat content.

In line with previous studies with mechanically pressed canola meal (Hristov et al., 2011) or RSC (Brask et al., 2013a,b; Bayat et al., 2022) replacing RSM, we did not observe differences in milk fat or protein concentrations or yields with our experimental diets. In contrast, Ramin et al. (2021) reported a linear decrease in milk fat and protein concentrations with a gradual replacement of barley with oats, but no differences in milk component yields were reported, and Fant et al. (2021) observed an increase in ECM yield and protein yield and a tendency for increased fat yield when barley was replaced with oats. Further, Vanhatalo et al. (2006) observed a greater milk protein concentration but no difference in other milk components in a diet with oats compared with diets supplemented with barley.

Gas Exchange

Methane production (g/d) and CH_4 intensity as g/kg ECM were lower ($P \leq 0.002$; Table 5) for RSC+O than for RSM+B. Similarly, CO_2, and H_2 emission, and O_2 consumption were lower ($P \leq 0.05$) for RSC+O compared with RSM+B.

Gas exchange data were collected using a GreenFeed unit incorporated in a milking robot, which does not allow the cows free access to visit outside their milking times (maximum 4 visits/d). Therefore, the absolute daily CH_4 production levels should be interpreted with some caution. However, the number of visits in the current study was high enough to achieve measurements with a reasonable variability and revealed relative treatment differences. Indeed, in line with our hypothesis, we observed a reduction in CH_4 production by 9.4% and CH_4 ECM intensity by 11.7%, respectively, for cows fed the RSC+O compared with RSM+B diet. The inhibitory effect of lipids on CH_4 formation in the rumen is well established (Ramin and Huhtanen, 2013; Arndt et al., 2022). Using the equations of Moate et al. (2011) and Patra (2013), the predicted reduction in CH_4 production based on the dietary lipid content of the experimental diets used in the current experiment would be around 5%, which is lower than the measured reduction (i.e., 9.4%, corresponding to around 0.14 g/d decrease in CH_4 production per gram of additional fat intake).

Previous experiments with an increased dietary lipid content by 1.2 to 2 percentage units through replacement of RSM with RSC have reported reduced CH_4 production by 0.08 to 0.10 g/d per gram of additional fat intake, and CH_4 yield or intensity (ECM-basis) by 7% to 12% (Brask et al., 2013a; Gidlund et al., 2017; Bayat et al., 2022). Similar reductions in CH_4 production of 0.09 g/d per gram of additional fat intake was reported, whereas CH_4 intensity (ECM-basis) decreased by 20%, when dietary lipid content was increased through inclusion of milled rapeseed and oats (Halmemies-Beauchet-Filleau et al., 2023).

In contrast, gradual replacement of barley with oats, and subsequent increase in dietary fat content from 2.7% to 3.6% of DM and iNDF content from 8.3% to 11%, resulted in 0.12 g/d decrease in CH_4 production per gram of additional fat intake, and a 4.4% and 4.8% in CH_4 yield (g/kg DMI) and intensity (g/kg ECM), respectively (Ramin et al., 2021). Replacing barley with hulled or dehulled oats did not affect CH_4 production (g/d) or yield (g/kg DMI), but CH_4 intensity (g/ kg ECM) was decreased by 5.7% when oat-based diets (hulled and dehulled oats) were fed (Fant et al., 2021).

Table 5. Gas exchange[1] of lactating cows fed rapeseed cake and oats or rapeseed meal and barley as concentrate feeds

Item	Treatment[2]			
	RSC+O	RSM+B	SEM[3]	*P*-value
CH_4, g/d	441	487	25.2	<0.001
CH_4, g/kg DMI	18.5	19.3	1.42	0.20
CH_4, g/kg ECM	11.3	12.8	0.55	0.002
CO_2, g/d	11,963	12,844	391	0.003
H_2, g/d	0.805	1.12	0.070	<0.001
O_2, g/d	8,631	8,961	329	0.05

[1]Measured using a GreenFeed unit incorporated in the automatic milking system; number of visits per measurement week: 16.1 ± 3.21 and 16.9 ± 3.29 for cows on RSC+O and RSM+B treatments, respectively.

[2]Experimental treatments were rapeseed cake and oats (RSC+O), or rapeseed meal and barley (RSM+B) as the concentrate feeds. The treatments were fed as a pelleted robot feed, and a PMR with grass silage and oats or barley.

[3]Largest SEM published in table; n = 33 (n represent number of observations used in the statistical analysis). Data are presented as LSM.

Overall, the results from the current study are well-aligned with previous experiments focusing on the effects of either RSC or oats, albeit showed a greater-than-expected reduction in CH_4 emissions. The different responses in production and CH_4 emission variables to lipid supplementation stem from various factors related to differences in experimental conditions, most importantly the DMI of the experimental cows, as well as fiber and fermentable carbohydrate contents of the experimental diets (Patra, 2013). The reduced CH_4 production and intensity in cows fed the RSC+O diet in the current study were largely due to the decrease of rumen fermentable carbohydrates, as a consequence of reduced OM intake and digestibility, and subsequent reduction in the rate of methanogenesis (Ramin and Huhtanen, 2013; Ramin et al., 2021). Fat supplementation has a combination of effects on rumen fermentation, and subsequently methanogenesis, as it usually leads to decreased DMI and OM digestibility, which in turn reduces the rate of methanogenesis. Simultaneously, UFA or medium-chain SFA, can also directly inhibit methanogenesis (Beauchemin et al., 2008). On top of the mitigating effect of additional lipids of the RSC+O diet, the greater indigestible fiber content of oats, and hence provision of less fermentable OM (Ramin et al., 2021), further enhanced the mitigation of CH_4 production in these cows. Indeed, Razzaghi et al. (2022), reported an interaction between dietary forage to concentrate ratio and lipid supplementation for CH_4 production (g/d); a greater reduction was observed in cows supplemented oil on a high forage diet than low forage diet. Thereby, the combined effect of lipids from RSC and oats, and less digestible fiber from oats may have resulted in the greater-than-expected reduction in CH_4 emission than would be expected from the additional lipid supply based on prediction equations (Moate et al., 2011; Patra, 2013) and previous experiments discussed above.

As expected, H_2 emission decreased by 28% with RSC+O diet, which is in line with Halmemies-Beauchet-Filleau et al. (2023) who replaced RSM and barley with milled rapeseed and oats. The reduced CO_2 production in RSC+O fed cows further supports the results indicating a decreased OM fermentation in the rumen. This is in line with Ramin et al. (2021), who also reported a decreased CO_2 production when barley was gradually replaced by oats. However, the decreased digestibility did not lead to reduced lactational performance of cows in the current experiment, as discussed above.

CONCLUSIONS

Including rapeseed cake and oats in a grass silage–based diet showed a tendency for enhanced milk yield and improved both feed and milk ME efficiency, whereas milk component and ECM yields were not affected. In line with our hypothesis, inclusion of rapeseed cake and oats decreased CH_4 production (g/d) and intensity (g/kg ECM) by 10% and 12%, respectively, compared with a diet containing rapeseed meal and barley. However, the extent of the decrease was greater than expected based solely on the dietary fat content. The reduction in CH_4 emission was most likely caused by decreased DMI in combination with reduced OM digestibility due to greater supply of lipids from rapeseed cake and oats, and indigestible fiber from oats. The tested diet would provide a practical way of mitigating enteric CH_4 emission from dairy operations while increasing the production efficiency of the cows.

NOTES

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Nonstandard abbreviations used: AIA = acid insoluble ash; EE = ether extract; MY = milk yield; PMR = partial mixed ration; RSC = rapeseed cake; RSC+O = PMR with oats and the pelleted robot feed containing RSC and oats; RSM = rapeseed meal; RSM+B = PRM with RSM and barley as the pelleted robot feed.

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