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Replacing wheat with canola meal and maize grain in the diet of lactating dairy cows: Feed intake, milk production and cow condition responses

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This research paper describes the effect of partially replacing wheat with maize grain and canola meal on milk production and body condition changes in early lactation Holstein-Friesian dairy cows consuming a grass silage-based diet over an 83-d period. Two groups of 39 cows were stratified for age, parity, historical milk yield and days in milk (DIM), and offered one of two treatment diets. The first treatment (CON) reflected a typical diet used by Western Australian dairy producers in summer and comprised (kg DM/cow per d); 8 kg of annual ryegrass silage, 6 kg of crushed wheat (provided once daily in a mixed ration), 3·6 kg of crushed lupins (provided in the milking parlour in two daily portions) and ad libitum lucerne haylage. The second treatment diet (COMP) was identical except the 6 kg of crushed wheat was replaced by 6 kg of a more complex concentrate mix (27% crushed wheat, 34% maize grain and 37% canola meal). Lucerne haylage was provided independently in the paddock to all cows, and no pasture was available throughout the experiment. The COMP group had a greater mean overall daily intake (22·5 *vs* 20·4 kg DM/cow) and a higher energy corrected milk (ECM) yield (29·2 *vs* 27·1 kg/cow; $P = 0{\cdot}047$) than the CON cows. The difference in overall intake was caused by a higher daily intake of lucerne haylage in COMP cows (4·5 *vs* 2·3 kg DM/cow). The CON group had a higher concentration of milk fat (42·1 *vs* 39·3 g/kg; $P = 0{\cdot}029$) than COMP cows. Milk protein yield was greater in COMP cows ($P < 0{\cdot}021$); however, milk fat yield was unaffected by treatment. It is concluded that partially replacing wheat with canola meal and maize grain in a grass silage-based diet increases voluntary DMI of conserved forage and consequently yields of ECM and milk protein.

Keywords: Dairy cows, grass silage, wheat, maize grain, canola meal.

Extracting maximum value from high cost supplements is critical to the profitability of dairy farming in Australia. On pasture-based dairy farms in South-Western Australia, the Mediterranean-type climate prevalent in the region means high levels of conserved forage and concentrate supplements are used, as grazed pasture is typically only available on dryland farms between April and December (McDonnell et al. 2017). The lower metabolisable energy (ME) and crude protein (CP) content of grass silage (generally the main supplementary forage used in the region) in comparison to fresh pasture, means the feeding of greater levels of concentrate is necessary in the non-grazing season to maintain milk production. Wheat and barley are the most common cereal grain supplements used, while lupin grain, and to a lesser extent canola meal, are the main protein supplements (McDonnell et al. 2017).

Numerous recent experiments have investigated milk production responses to feeding different combinations and amounts of mixed rations to cows on pasture-based dairy systems (Auldist et al. 2013, 2014; Golder et al. 2014). It has also been shown that the same milk production advantages observed with a mixed ration can be achieved when the formulated grain mix component of the ration is fed in the parlour (Wales et al. 2013; Auldist et al. 2016). Traditionally in South-Western Australia, concentrates are fed to dairy cows in the parlour during milking. However, if not managed correctly, high concentrate diets can compromise cow health and milk production, often as a result of ongoing subclinical acidosis (Krause & Oetzel, 2006). An alternative approach is to provide some or all concentrates in combination with conserved forages, a similar method to

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that often used on pasture-based farms where a partial mixed ration (PMR) with conserved forages and concentrates is fed between periods of grazing (Bargo et al. 2002).

Auldist et al. (2013) found that energy corrected milk (ECM) production responses were greater when a more complex ration was fed that contained lucerne hay, maize silage, and maize grain compared with diets comprising barley grain and pasture silage, at supplement intake amounts of >10 kg DM/cow per d. These authors attributed this ECM response to the maize grain and maize silage component of the ration. A notable finding from this experiment was the greater milk fat concentration when maize grain was fed at high levels of concentrate intake. In addition, Auldist et al. (2014, 2016) and Golder et al. (2014) reported that replacing a portion of wheat with canola meal had a positive effect on DM intake (DMI) and consequently ECM production, possibly due to a more balanced amino acid (AA) profile (Huhtanen et al. 2011).

These experiments, however, were conducted in an environment where grazed pasture formed the main forage component of the diet. Limited information exists as to the efficiency of canola meal and maize grain supplementation where grass silage is the main forage component and no fresh pasture is available. Therefore, the aim of this experiment was to investigate whether partially replacing wheat with maize grain and canola meal in a mixed ration with grass silage, where both treatments were also provided with lupins in the parlour and ad libitum lucerne haylage independent of the mixed ration, had benefits in terms of increased production and performance. Our hypothesis was that the inclusion of canola meal and maize grain would result in a greater intake of lucerne haylage and increased milk production, as well as a greater milk fat concentration. In addition, the performance of both treatment groups was modelled using the Cornell Penn Miner (CPM) dairy ration formulation software (Tedeschi et al. 2008), to provide a better insight into mechanisms behind the response.

Materials and methods

This experiment was approved by the Department of Agriculture and Food Western Australia Animal Ethics Committee (Approval no: 15-1-03) and was conducted at the Vasse Research Centre (VRC, 33°45′S, 115°21′E, elevation 30 m), approximately 15 km south of Busselton in South-Western Australia.

Animals

Seventy-eight lactating cows were divided into two treatment groups of 39 (29 multiparous and 10 primiparous) and balanced (mean ± SD) according to age (months; 51 ± 19), parity (2·7 ± 1·4) and days in milk (DIM; 25 ± 11). Multiparous cows were also stratified to treatment according to previous lactation daily milk yield (mean 21·0 L ± 4·5), daily milk fat and protein yield (mean 1·46 kg ± 0·31) and previous lactation length (mean 344 d ± 55). Treatments were applied over an 83-d period from 25 March 2015–16 June 2015, and d 1 of the experiment equated to 25 DIM. The cows were predominantly Holstein Friesian (HF) or HF crosses, with a small number of Brown Swiss allocated equally to each treatment. Cows were milked twice daily at 07·00 and 15·00, and both groups were located in equal sized 'sacrifice' paddocks within 500 m of the milking parlour. Artificial shade was provided from the beginning of the experiment until 30 April 2015, in order to limit the effects of heat stress on milk production.

Diets and feeding

Dietary composition for each treatment (kg DM/cow per d) is outlined in Table 1. The CON diet was formulated to reflect a typical summertime diet used by dairy farmers in the region. Grass silage and all concentrates except lupins were fed once daily in a mixed ration using an *Italmix* mixer wagon (Italmix Srl, Ghedi Italy) at approx. 08·00 (immediately after AM milking) to each treatment on a group basis using round tombstone feeders. One litre of water per kg of fresh weight concentrate was added to each mix to obtain a ration DM content of approx. 450 g/kg. The lucerne haylage was provided ad libitum on a group basis to each treatment in the paddock, separately to the mixed ration (but also in round tombstone feeders) with unrestricted equal access for all cows throughout the experiment. Lupins were provided individually to each cow in the parlour in equal amounts at AM and PM milking. A commercially available mineral mixture (*Lac Cow 30 Mon + Acid Buff*; Advanced feeds Pty Ltd, Midland WA 6936, Australia) was supplied to all cows at a daily rate of 200 g/cow in the mixed ration. Data recording commenced on d 1 and was preceded by a dietary adaptation period of 6 d.

Feed analysis

Samples of all feed components from each treatment were collected twice weekly, and then pooled weekly for nutritional composition analysis. Dry matter content was measured by drying a subsample of fresh material at 100 °C for 24 h. Loss of volatile compounds in silage DM during oven drying was corrected for using the following equation:

$$\text{True DM\%} = 3 \cdot 96 + (0 \cdot 94 \times \text{Oven DM\%});$$

(Kaiser et al. 1995)

Ash was determined by ashing samples in a muffle furnace at 600 °C for 10 h. Feed DM and organic matter (OM) digestibilities were measured using a pepsin-cellulase in vitro method (Aufrere & Michalet-Doreau, 1988), from which organic matter digestibility (OMD) and ME were calculated as outlined by the Standing Committee on Agriculture (1990). Total nitrogen (N) in DM was measured using the Kjeldahl method (AOAC, 1990; method #976.06), and CP was calculated as N × 6·25. Neutral detergent fibre (NDF) content was determined as described by

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Table 1. Treatment diets, nutritive characteristics of feeds used, and concentration of selected essential amino acids

	Grass silage	Wheat	Maize grain	Canola meal	Lupins	Lucerne haylage
Treatment						
CON (kg DM)	8·0	6·0	0	0	3·6	Ad libitum
COMP (kg DM)	8·0	1·6	2·2	2·2	3·6	Ad libitum
Nutritive characteristics						
DM (g/kg)	436	902	901	942	896	633
CP (g/kg DM)	104	119	95	323	320	243
NDF (g/kg DM)	546	124	94	323	244	406
DMD (g/kg DM)	654	810	891	895	870	737
Ash (g/kg DM)	77	24	14	57	27	106
Fat (g/kg DM)	37	21	42	182	64	29
Starch (g/kg DM)	5	639	697	6	11	9
ME (MJ/kg DM)	10·0	12·7	14·2	13·5	13·6	10·7
Amino acid content (% of CP)						
Histidine	ND	ND	ND	2·6	2·6	ND
Arginine	ND	ND	ND	4·9	8·0	ND
Threonine	ND	ND	ND	5·5	4·6	ND
Lysine	ND	ND	ND	5·9	4·8	ND
Methionine	ND	ND	ND	1·6	0·4	ND

CON, control; COMP, formulated grain mix; CP, crude protein; NDF, neutral detergent fibre; DMD, dry matter digestibility; ME, metabolisable energy; ND, not determined.

Van Soest et al. (1991). The starch and fat content of all feeds was determined via wet chemistry by a commercial laboratory (Dairy One, 730 Warren road, Ithaca NY, USA). In addition, the AA composition of the two high-protein concentrates, canola meal and lupins, was measured in duplicate using representative bulk samples. Samples underwent 24 h liquid hydrolysis in 6 M hydrochloric acid at 110 °C (Australian Proteome Analysis Facility, Macquarie University, Sydney, NSW 2109, Australia). Details of the chemical composition of each feed component are shown in Table 1.

A separate, single wet chemistry analysis of each feed component (bulked representatively throughout the 12-week experimental period using twice weekly samples) was carried out by Dairy One to generate an average chemical composition profile for each dietary ingredient to input into CPM Dairy.

Data collection

Daily individual milk yield was recorded for each cow (AM and PM) for the duration of the experiment using DeLaval milk meters. Milk composition data was obtained on d 19, 47 and 75 of the experiment (44, 72 and 100 DIM). Individual milk fat and milk protein concentration from each animal was measured using an infrared milk analyser (Farmwest Herd Recording Services, Bunbury WA 6230, Australia). Milk energy was calculated according to Tyrrell & Reid (1965) using the following formula:

$$\text{Milk energy(kJ/kg)} = (38\cdot4\times\text{fat g/kg}) + (22\cdot26\times\text{protein g/kg}) + (19\cdot92\times\text{lactose g/kg}) - 108\cdot1$$

Energy corrected milk (kg) was then calculated based on a standardised kilogram of milk containing 40 g/kg fat, 30 g/kg protein, and 50 g/kg lactose, which has an energy content of 3092 KJ/kg according to the above equation.

Milk urea nitrogen (MUN) concentration of milk from each group was analysed twice weekly (AM and PM samples) using a proportionate composite sample from each treatment group from d 35–83 (60–108 DIM) of the experiment. An adaptation of an assay routinely used in a commercial laboratory (Bunbury Pathology Pty Ltd, Bunbury, WA 6230, Australia) to measure blood urea nitrogen was used to calculate MUN concentration of milk samples. The method was validated for bovine milk samples by adding known amounts of urea to a raw milk sample and diluting raw milk with known amounts of distilled water in order to obtain five different urea concentrations in the raw milk sample ranging from 2 to 10 mmol/l. A regression analysis of the measured milk urea concentrations against the known urea content of each sample resulted in an r^2 of 0·99 (slope of regression: $y = 1{\cdot}02x$).

Each morning, refusals of mixed ration (if any) were collected for each treatment, weighed and sampled for DM content. Dry matter intake of mixed ration was consequently calculated daily on a group basis for each day. Lucerne haylage DMI for each treatment was also calculated on a group basis in a similar manner, to give a daily DMI of lucerne haylage per group for each experimental day. Lucerne haylage was available ad libitum throughout the experiment and refusals were recorded daily. There were no refusals of lupins observed in the milking parlour throughout the experiment.

Bodyweight and body condition score

Bodyweight (BW) of all cows was recorded individually on d 1, 27, 57, 82 and 83 of the experiment (25, 52, 82, 107 and 108 DIM respectively) at approximately 09:00 each day. Body condition score (BCS) was also assessed for each animal on d 1, 28, 58, and 82 by the same experienced technician at all times according to the 8 point scale of Earle (1976). On d 82, BCS of each cow was recorded twice, about an hour apart, and averaged to give a more accurate assessment of BCS at the end of the experiment.

Analysis of diets and performance using modelling software

Diets and performance from both treatments were evaluated using the ration formulation program CPM Dairy (Version 3.0.8; Cornell University, Ithaca, NY, USA; University of Pennsylvania, Kennett Square, PA, USA; William H. Miner Agricultural Research Institute, Chazy, NY, USA; Tedeschi et al. 2008). Mean measured intake, weight change, milk production and composition, environmental and management parameters for each treatment over the 83-d experimental period were entered into the model.

Statistical analysis of results

Daily yields of milk, ECM, fat and protein were averaged for each individual animal over 2-week periods throughout the experiment, generating six timepoints. These data were analysed using the repeated measures ANOVA procedure in Genstat (GENSTAT release 17, VSN International, Hemel Hempstead, UK), and significances were declared at $P < 0{\cdot}05$. Weight and BCS differences were analysed in a similar manner using each timepoint as a repeated measure (four per animal). Differences in milk fat and protein concentration between treatments were also analysed using repeated measures ANOVA at three different sampling points. As DMI was calculated on a group basis for each treatment, statistical analysis of feed intake related parameters was not possible. Daily means of total group DMI and lucerne haylage group DMI over six 2-week periods were used to illustrate changes in intake between treatments throughout the experiment (Fig. 1).

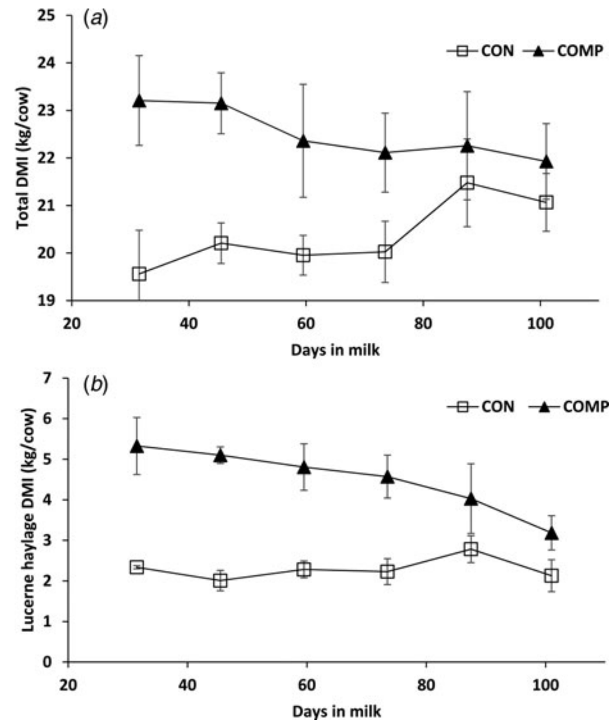

Fig. 1. Daily total group DMI (a), and daily group DMI of lucerne haylage only (b). Data are presented as means of daily intake across 2-week periods. Error bars represent SD of daily group DMI. CON, wheat and grass silage in mixed ration with lupins provided in-parlour; COMP, wheat/maize grain/canola meal and grass silage in mixed ration with lupins provided in-parlour. Both treatments also had *ad libitum* access to lucerne haylage.

Results

Figure 1a shows that the mean total daily DMI for the COMP group throughout the experiment was 22·5 kg DM/cow (SD = 1·04) while for the CON group it was 20·4 kg DM/cow (SD = 0·95). By design, this difference was driven solely by daily DMI of lucerne haylage (Fig. 1b) which averaged 2·3 kg DM/cow in the CON group, *vs* 4·5 kg DM/cow in the COMP group, while mean daily group DMI of mixed ration was very similar for both treatments (14·5 *vs* 14·4 kg DM/cow for CON *vs* COMP cows). Mean daily lupin DMI was the same for all treatments at 3·6 kg DM/cow.

There was no time by treatment interaction detected for any milk related variable. Changes in mean daily milk yield throughout the experiment are shown in Fig. 2. Overall, milk yield/cow was significantly higher ($P = 0{\cdot}002$) in the COMP treatment compared with the CON treatment (Table 2). However, mean milk fat concentration was significantly lower ($P = 0{\cdot}027$) for the COMP treatment. This resulted in the difference in mean ECM production between the treatments being of a lower magnitude than the difference in milk yield, however it was still significantly greater in the COMP cows ($P = 0{\cdot}047$), compared with the CON treatment. Because of the higher milk fat concentration in the CON treatment, the difference in mean milk fat yield between treatments was not significant ($P = 0{\cdot}24$); however, milk protein yield was significantly higher for the COMP treatment ($P = 0{\cdot}021$).

The interaction between treatment and time for BCS was significant ($P = 0{\cdot}008$), as shown in Fig. 3a where BCS was 0·2 units greater at 52 and 0·3 units greater at 82 DIM for the COMP cows. Mean BW throughout the experiment was 565 and 573 kg for CON and COMP cows respectively and did not differ between treatments ($P > 0{\cdot}05$).

Milk urea nitrogen concentration of both treatments from d 35 (60 DIM) to the end of the experiment are detailed in Fig. 3b. Mean MUN concentration of animals in the

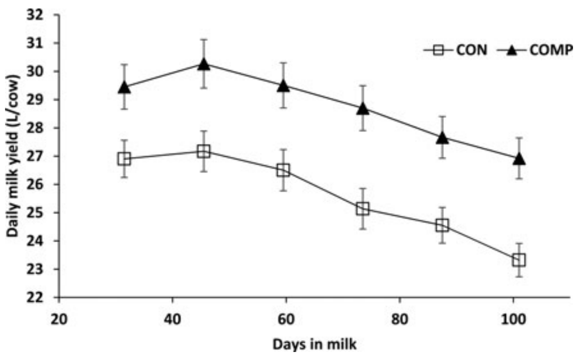

Fig. 2. Mean daily milk yield/cow for CON and COMP cows. Data are presented as means of individual daily milk yield across 2-week periods. Error bars represent SEM of daily milk yield/cow. CON, wheat and grass silage in mixed ration with lupins provided in-parlour; COMP, wheat/maize grain/canola meal and grass silage in mixed ration with lupins provided in-parlour. Both treatments also had *ad libitum* access to lucerne haylage.

Table 2. Differences in daily milk yield and milk composition between CON and COMP cows over the 83-d experimental period

Variable[†]	CON $n=39$	COMP $n=39$	SEM	*P*-value
Milk yield (L/cow)	28·8	25·6	0·71	0·002
Milk fat (g/kg)	42·1	39·3	0·89	0·029
Milk protein (g/kg)	30·3	29·4	0·33	0·057
ECM yield (kg/cow)	27·1	29·2	0·75	0·047
Milk fat yield (kg/cow)	1·11	1·17	0·034	0·241
Milk protein yield (kg/cow)	0·80	0·87	0·022	0·021

ECM, energy corrected milk corrected to 40 g/kg fat, 30 g/kg protein and 50 g/kg lactose

CON, wheat and grass silage in mixed ration with lupins provided in parlour; COMP, wheat/maize grain/canola meal and grass silage in mixed ration with lupins provided in-parlour. Both treatments also had *ad libitum* access to lucerne haylage.

†Differences between treatment means were tested by repeated measures ANOVA. No interaction between treatment and time was detected for any milk related variables ($P > 0·05$).

COMP group was significantly higher than the CON group (6·2 *vs* 4·9 mmol/l; SEM = 0·16; $P < 0·001$).

Table 3 shows the output from CPM Dairy modelling of the diets over the 83-d period for both the CON and COMP groups. The model showed that the NDF, CP, and ether extract (EE) contents of the COMP diet were higher, and the starch content substantially lower, than the CON diet.

Discussion

The first hypothesis tested in this experiment was that replacing a portion of wheat with canola meal and maize grain in early lactation cows consuming a traditional Western Australia (WA) summer diet of wheat, grass silage and lupin grain would result in greater DMI and milk production. This was supported by the results observed, with the COMP cows consuming, on a group basis, a daily average of 2·2 kg DM/cow more feed throughout the experiment than the CON cows.

The underlying biological mechanism behind the apparent increased DMI of the COMP treatment is unclear. An increase in DMI of cows consuming pasture supplemented with a PMR containing canola meal has also been reported by Auldist et al. (2014), at similar rates of daily concentrate consumption to the 9·6 kg DM/cow consumed in our experiment. Earlier work by Allen et al. (2006) suggested that high protein feeds, such as canola meal, may have a greater buffering capacity in the rumen than low protein feeds, thus stabilising ruminal fluid pH to a larger degree and stimulating a greater inclination to eat.

Milk production was significantly higher in the COMP cows, which was unsurprising given the difference in DMI. However, it is unclear if the entire difference in milk production between treatments was due to the extra lucerne haylage consumed, or if the feeding of canola meal or maize grain also contributed to the increased milk production response. Modelling of the diets using CPM Dairy showed the dietary CP level of the COMP group

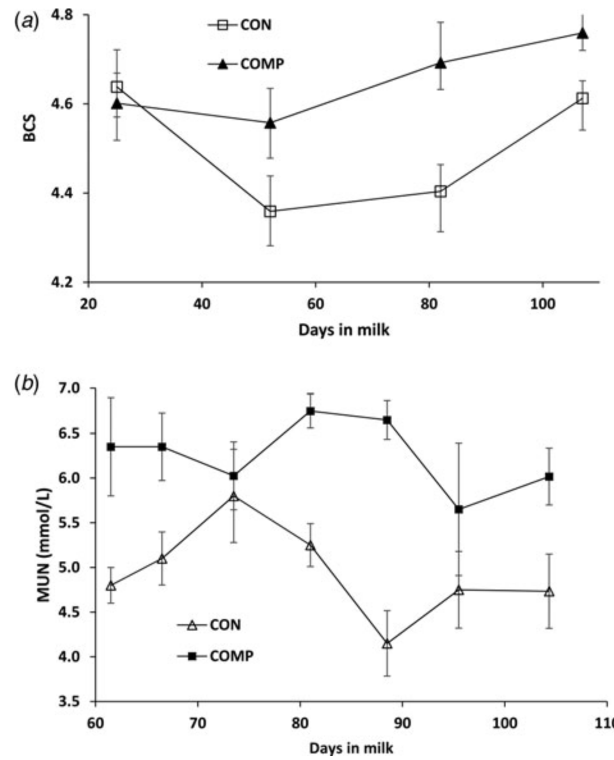

Fig. 3. Effect of two different mixed rations on (a) mean BCS from 25–108 d in milk (DIM); and (b) mean weekly milk urea nitrogen (MUN) concentration from 60–108 DIM. Error bars represent SEM. CON, wheat and grass silage in mixed ration with lupins provided in parlour; COMP, wheat/maize grain/canola meal and grass silage in mixed ration with lupins provided in-parlour. Both treatments also had *ad libitum* access to lucerne haylage.

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Table 3. Effect of two different mixed rations on key dietary parameters and modelled performance and production levels using CPM Dairy

	CON	COMP
CPM Dairy cow details[†]		
Total DMI (kg/cow per d)	20·3	22·5
Dietary ME density (MJ/kg DM)	11·3	11·0
Measured milk production (kg/cow per d)	25·6	28·8
Dietary CP (%)	17·0	19·8
Soluble protein (% CP)	44·4	46·5
RUP (% CP)	28·0	30·3
RDP (% CP)	72·0	69·7
ADF (%)	24·7	27·6
NDF (%)	35·0	38·0
Starch (%)	20·1	11·8
Ether extract (%)	3·0	4·9
NFC (%)	41·8	34·4
Lignin (%)	3·2	4·2
Ash%	5·7	6·3
CPM Dairy model predictions[‡]		
Est. available ME (MJ/cow per d)	229	248
Required ME (MJ/cow per d)	221	242
ME Balance (MJ/cow per d)	8	6
Composition constant ME allowable milk (kg/cow per d)	27·2	30·0
Est. available MP (g/cow per d)	2139	2266
Required MP (g/cow per d)	2053	2311
MP balance (g/cow per d)	86	−45
Composition constant MP allowable milk (kg/cow per d)	27·4	27·8
Predicted rumen pH	6·46	6·46

CON, wheat and grass silage in mixed ration with lupins provided in parlour; COMP, wheat/maize grain/canola meal and grass silage with lupins provided in-parlour. Both treatments also had *ad libitum* access to lucerne haylage.
DMI, dry matter intake; ME, metabolisable energy; RUP, ruminally undegradable protein; RDP, ruminally degradable protein; NFC, non-fibre carbohydrates; MP, metabolisable protein.
†Diet details are based on analysis of composite samples of each individual feed ingredient used in the experiment by Dairy One laboratories (Ithaca, NY, USA) using a wet chemistry, ration-formulation model profile.
‡Model predictions are based on mean measured milk production, weight gain and environmental conditions throughout the experimental period.

was 2·8% higher than the CON group. It is reasonable to assume that some portion of the increase in milk production was due to the higher CP intake of the COMP cows, as previous research has shown improved milk yield responses following the provision of canola meal and other protein supplements at iso-energetic levels of intake to un-supplemented control groups (Ipharraguerre & Clark, 2005; Huhtanen et al. 2011).

A further explanation for the differences observed here may be that the additional CP provided by the canola meal resulted in a more balanced supply of AA in the COMP cows, enhancing milk production and energy demand and therefore increasing DMI (Huhtanen et al. 2011). A negative effect of histidine (His) deficiency on lactating cow DMI was previously reported by Lee et al. (2012) and this was backed up by a recent study from Giallongo et al. (2017), which showed cows fed a diet deficient in His (1·9 *vs* 2·5% of MP) had a lower intake of 1·7 kg DM/d and a lower milk yield. Vanhatalo et al. (1999) reported that abomasal infusion of His in cows with unlimited access to grass silage containing 140 g/kg CP and also receiving 8 kg/cow per d of cereal based concentrates containing 120 g/kg CP, resulted in significant increases in milk production at the same level of DMI as un-supplemented controls. These authors concluded His is the first limiting AA when grass silage-based diets are supplemented with cereal concentrates. In the current experiment, the His content of canola meal was similar to published values (NRC, 2001); therefore it's possible the extra His supplied to the COMP treatment in the canola meal may have contributed to the increased milk yield.

In most cases ME intake is the primary factor limiting milk production in dairy cows (Hills et al. 2015), an effect which has been demonstrated at comparable levels of concentrate supplementation to the ones used in the current experiment (Auldist et al. 2014). However, the CPM Dairy modelling used in the current experiment suggested that in the COMP group, availability of MP was actually a greater limiting factor than ME availability. Total supply of AA has been shown to limit milk production on pasture based diets when low-protein cereal grain is the primary supplement (Hills et al. 2015). It was surprising that the CPM Dairy model indicated MP availability was the primary limiting factor affecting milk production in the COMP group, given the high CP content of the diet, but the higher soluble protein content, caused by the greater intake of lucerne haylage, may have contributed to this.

Our second hypothesis was that replacing part of the wheat with maize grain and canola meal would have milk production benefits in terms of increased milk fat concentration and greater relative ECM production. However this effect was not observed at any stage throughout the experiment, and therefore this hypothesis was rejected. Indeed, milk fat concentration in the CON group was consistently higher by approx. 3 g/kg throughout the 12-week experimental period. This was surprising as CPM Dairy indicated the NDF content of the diet was higher in COMP cows than CON cows, though both were with recommended ranges (NRC, 2001). The dietary fat content of 49 g/kg in the COMP group was almost 20 g/kg higher than in the CON group and this may have impaired fibre digestion and consequently affected milk production (Bauman & Griinari, 2003), although these authors also suggested that this is likely to be an issue when total dietary fat exceeds 50 g/kg.

The starch present in maize grain has been found to degrade more slowly in the rumen than wheat (Khorasani et al. 2001), which theoretically should help reduce diurnal fluctuations in rumen pH, or more specifically limit the amount of time that rumen pH is below 6·0, a threshold that has previously been shown to have negative effects on milk production through impaired NDF digestion

(Leddin et al. 2010). However, milk production responses when maize grain was substituted for other cereal based concentrates in previous studies have been equivocal. It seems the total amount of starch-based concentrate consumed plays a major role in the effect of maize grain supplementation on milk yield. Both O'Mara et al. (1997) and Wales et al. (2013) showed minimal milk yield benefits when maize grain was substituted for other cereal grains at moderate levels of total concentrate intake (up to 8 kg DM/d). In contrast, Auldist et al. (2013) reported higher yields of ECM, due largely to a higher milk fat concentration, in late lactation cows consuming pasture and a PMR of maize grain, maize silage, milled barley grain and lucerne hay when compared to an iso-energetic control group consuming milled barley grain and grass silage. However, these differences were only observed by Auldist et al. (2013) at higher levels of daily intake (>7·5 kg of cereal grain/cow). In the current experiment, it is likely that the total amount of cereal grain consumed by the COMP and CON groups (4 and 6 kg DM/cow per d respectively) was insufficient for the maize grain to positively affect milk production. The starch content of the total diet consumed by the COMP group was relatively low at 120 g/kg, while it was 200 g/kg for the CON cows. A recent review by Hills et al. (2015) showed that on average, supplementation with 1 kg DM of starch-based concentrate increases milk protein concentration by 0·01%. Starch fermentation in the rumen favours propionate production and results in increased levels of circulating insulin, which in turn leads to a greater uptake of AA by the mammary gland (Griinari et al. 1997; Hills et al. 2015). In the current experiment milk protein concentrations were lower in the COMP group, although the differences were small, indicating that starch supply in the rumen may have been a limiting factor to milk protein synthesis.

The mean MUN concentrations for both CON and COMP cows (4·9 and 6·2 mmol/l respectively) were within normal parameters of 4·5–6·5 mmol/l (Nousiainen et al. 2004), indicating that excess CP supply was not a major issue in these cows, although mean weekly MUN concentrations of COMP cows did reach 6·8 mmol/l on d 55 (80 DIM) of the experiment, suggesting excess ruminally degradable protein (RDP) may have been a factor at this stage. It is well established that increasing intakes of lucerne haylage in dairy cows can result in higher MUN concentrations, due to a greater proportion of soluble protein and non-protein nitrogen (NPN) in lucerne haylage (NRC, 2001) which is rapidly degraded into ammonia in the rumen and subsequently converted into urea (Nousiainen et al. 2004).

Body condition score is an important factor affecting milk production, health, welfare and reproductive function (Roche et al. 2009), and is also considered a more suitable measure than BW to monitor changes in body reserves in early lactation cows in a state of negative energy balance (Berry et al. 2006). This is because changes in adipose and lean tissue weight can be masked by enhanced gastrointestinal fill, caused by feed intake increases in early lactation (Andrew et al. 1994; Roche et al. 2009). Whilst our results showed the rate of BCS loss was greater in CON treatment compared to the COMP treatment, the differences were not sufficiently large to have biological significance. However, a longer-term experiment would be required to more accurately account for the implications of the differing BCS changes observed here between treatments on performance and reproductive function.

Conclusions

Notwithstanding the limitations of measuring treatment DMI on a group basis, replacing a portion of wheat with canola meal and maize grain in early lactation cows fed a mixed ration resulted in a 2·2 kg DM increase in total daily DMI of lucerne haylage. Milk yield was consequently shown to be significantly greater in these cows throughout the experiment. A more balanced supply of AA, due to the presence of canola meal in the COMP treatment diet, may partly explain the apparent enhanced desire to eat in these cows. Recent research has shown that in diets based on grass silage and cereal grain, milk yield may be limited by the availability of His (Giallongo et al. 2017).

The moderate amount of cereal-based concentrate provided to the COMP treatment may have tempered the contribution of maize grain to the observed effects; hence further studies are warranted of a dose response nature using both canola meal and maize grain to elucidate the optimum amount of each ingredient to maximise productive efficiency, as well as determine the relative contribution of both dietary components to the increases in DMI and milk yield observed here.

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