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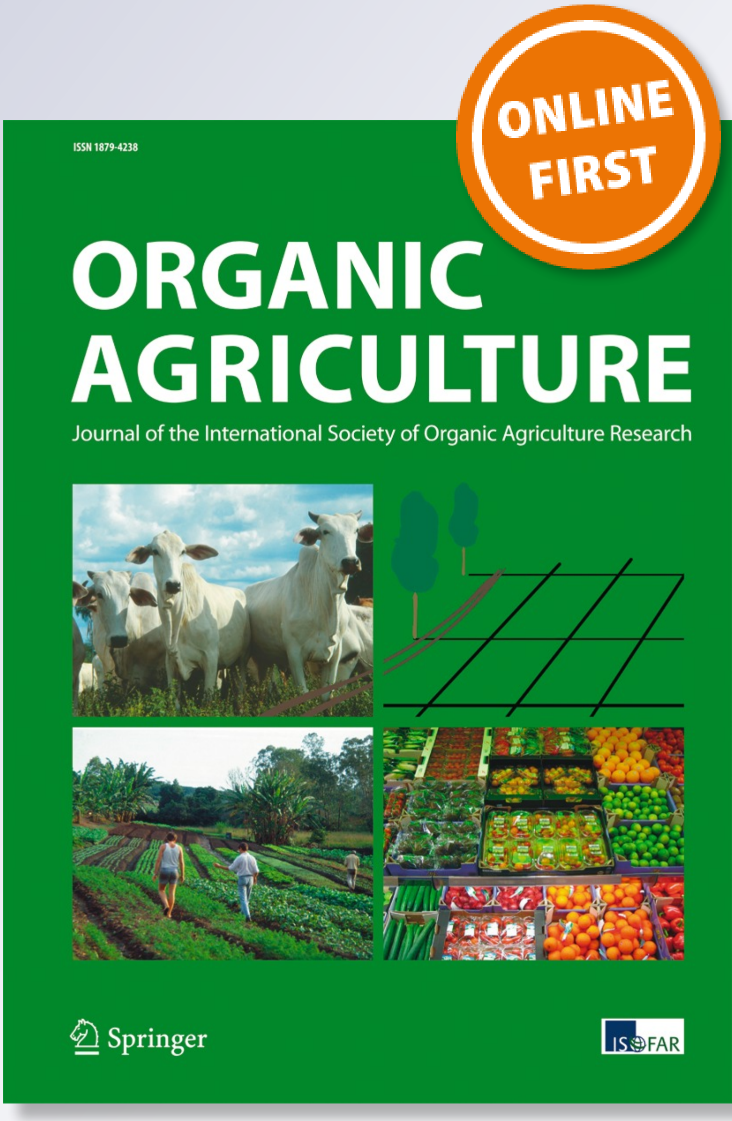

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Cold-pressed rapeseed cake or full fat rapeseed to organic dairy cows—milk production and profitability

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Abstract The interest in growing and feeding locally produced feeds is increasing. Case studies in Sweden have shown that feeds grown on-farm are more environmentally favourable than imported feeds, partly due to the lower energy requirements for transport. Full fat rapeseed (FFRS) and its co-product cold-pressed rapeseed cake (CRC) can both be locally produced, and CRC has been proven to be suitable for dairy cows. In both feeds, fat content limits the amount that can be supplemented in the diet, and less FFRS than CRC can be used. However, in a previous study with scenario calculations, CRC showed lower profitability than FFRS. The present study examined how milk yield and milk composition were influenced by feeding FFRS compared with CRC in organic diets and calculated the farm profitability on each occasion. The study was performed using 56 Swedish Holstein cows in different lactation stages. Diets were 100 % organic, including a mixed ration (silage, grains and minerals) fed ad libitum and a restricted amount of concentrates (field beans together with either CRC or ground FFRS). There were no significant differences in milk yield and composition between the diets. However, cows fed FFRS had a higher intake of the mixed ration than cows fed CRC. Cows fed CRC had the highest profitability in later lactation, whereas the diets were economically similar during early lactation.

Keywords Cake · Dairy cow · Organic milk production · Profitability · Rapeseed

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Introduction

A basic tenet of organic production is to provide farm animals with home-grown products, and thus interest in growing and using locally produced feeds is increasing. Case studies in Sweden have shown that feeds grown on-farm have less impact on the environment than imported feeds, partly due to the lower energy requirements for transportation (Strid and Bertilsson 2010) and lower greenhouse gas emissions (Flysjo et al. 2008). It may also be economically beneficial for farmers to include more home-grown protein in dairy cow diets (Gustafsson et al. 2014). The supply of fibre and protein, especially rumen undegradable protein, is a great challenge in composing diets with large amounts of home-grown feeds. Protein in locally produced protein feeds, such as legumes and oilseeds, often contains easily degradable protein, which may lead to decreased milk yield in early lactation in comparison to feeds containing more undegradable protein (Wu and Satter 2000). In addition, overfeeding of rumen degradable protein may lead to N surplus and a negative effect to the environment (Jonker et al. 2002; Børsting et al. 2003).

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Oilseeds in dairy cow diets are known to improve milk fatty acid (FA) profile by increasing concentrations of nutritionally desirable FA (Chilliard and Ferlay 2004; Woods and Fearon 2009). New varieties of rapeseed with low concentrations of anti-nutritional substances are readily available (Official Statistics of Sweden 2012). Comparisons between rapeseed meal and soybean meal have shown similar production, and the question of underestimation of metabolisable protein concentration in rapeseed meal was raised (Huhtanen et al. 2011; Martineau et al. 2013). The amino acid composition in rapeseed is superior to that in soybean, which has been shown to affect the concentrations of individual amino acids in cows' blood (Rinne et al. 2012; Maxin et al. 2013), and the total essential amino acid concentration was higher in cows fed canola meal than soybean meal (Maxin et al. 2013). In particular, plasma concentration of methionine was higher and milk urea concentration lower in cows fed rapeseed compared with cows fed soybean, indicating better nitrogen (N) use efficiency for rapeseed (Rinne et al. 2012; Maxin et al. 2013). In recent years, interest in oilseeds has increased, since (i) feeding supplementary fat diminishes methane emissions from cows (Beauchemin et al. 2009; Moate et al. 2011) and (ii) there is an increasing interest in biodiesel production from agricultural crops (Hristov et al. 2011).

Full fat rapeseed (FFRS) has been shown to have a negative influence on rumen microbes due to toxic effects when fed in excessive amounts, and its high fat content limits the amount that can be used in the diet (Sutton and Morant 1989; Jenkins 1993). Consequently, high fat diets are shown to increase the proportion of propionic acid and lower the synthesis of fatty acids in the rumen and could thereby depress milk fat content (Sutton and Morant 1989). Ground forms of full fat rapeseed have also been found to decrease dry matter (DM) intake compared to whole FFRS (Petit and Cortes 2010), but both whole and ground FFRS have inconsistent effects on milk yield, milk fat and protein contents (Beauchemin et al. 2009; Petit 2010; Lerch et al. 2012). The FFRS has a relatively slow release of fat compared with pure oils, and crushed FFRS can be fed in amounts of 1–2 kg per day with only small effects on cow metabolism (Murphy et al. 1987; Jenkins 1993). Cold-pressed rapeseed cake (CRC), which is a co-product of rapeseed oil production, can be produced locally and has been proven to be suitable for dairy cows (Johansson and Nadeau 2006), although only a few studies have reported the production response of CRC (Khalili et al. 1999; Johansson and Nadeau 2006; Lerch et al. 2012). In a study with scenario calculations, CRC was found to result in a lower financial output than FFRS (Mogensen 2004).

The aims of the present study were to determine how feed intake and milk yield and composition are influenced by feeding FFRS compared with CRC in organic dairy cow diets and to calculate the financial outcome of these diets.

Material and methods

Animals, experimental design and diets

The experiment was approved by the Research Animal Ethics Committee (Swedish Board of Agriculture) and performed during the indoor period 2009–2010 on 56 Swedish Holstein cows in different lactation stages at Tingvall organic dairy farm in south-west Sweden. The start-up day of the experiment was the same for all cows, irrespective of lactation stage. The rolling herd average annual milk yield was 10,842 kg per cow. The cows were housed in two treatment groups in a loose-house system. Cows were paired according to their expected calving date, lactation number and previous 305-day milk yield, or breeding index for heifers, and then randomly allocated to two treatments. The diet was 100 % organic, fed as a partially mixed ration (PMR) of grass-clover silage and rolled grains (a mixture of one-third each of barley, wheat and oats), a small amount of a commercial compound feed (fed due to low concentration of protein in silages) and mineral feed ad libitum, supplemented with a restricted amount of protein concentrate in the form of either CRC (treatment CAKE) or ground FFRS (treatment SEED), fed in transponder-controlled automatic feeders together with field beans in both treatments.

Cows were fed a minimum of 50 % forage in the diet, calculated on a DM basis, in the first three months after calving (1–90 days in milk, DIM) and thereafter a minimum of 60 % forage according to the standards for organic diets (EU 1999). Minerals and vitamins were fed according to Swedish recommendations, which are based on NRC (2001). Fat content in the total diet was used as the limiting factor for the amount of rapeseed used (approx. 5 % fat). When formulating the diets, the SEED diet had a somewhat higher energy content due to the high energy concentration in the FFRS. Apart from that, the diets were formulated for similar nutrient composition, with special emphasis on crude protein.

Data collection

Feed sampling Grass-clover forage was ensiled in bunker silos and was stored for at least 60 days before feeding. Silage samples were taken daily and pooled to one composite sample per week for analysis of DM and one sample per silo for analysis of nutrients on a DM basis as well as water-soluble carbohydrates (85 g per kg DM) and fermentation characteristics (Table 1). All concentrates were sampled once a week, and the samples were pooled to one composite sample per batch for chemical analyses (Table 1).

Feed analyses and calculations The DM concentration of silage was determined at 60 °C for 24 h (Volden 2011), while the DM concentration of concentrates was determined at 103 °C for 24 h (EU 2009). Crude protein (CP) and neutral detergent fibre (NDF) in forages and concentrates, crude fat in concentrates and fermentation characteristics of the silages were analysed at Eurofins Laboratories Inc. (Lidköping, Sweden), as described by Johansson and Nadeau (2006). Metabolisable energy (ME) concentration of silage was calculated from in vitro rumen organic matter digestibility. Metabolisable protein, expressed as amino acids absorbed in the small intestine (AAT) and protein balance in the rumen (PBV), was calculated from standards (Madsen et al. 1995). Analyses of soluble crude protein (sCP) and indigestible NDF (iNDF; scanned by near infrared (NIR)) in silage and calculations of net energy (NE) and AAT from feeds and microbes were performed according to Volden (2011).

Other recordings Feed intake of the mixed ration was recorded at group level, while protein concentrate intake was recorded individually. It was assumed that all cows in one treatment group had the same intake of the

Table 1 Chemical composition (mean and SD) of feeds used in the experiment: grass-clover silage n=4, grains n=2, commercial compound feed (CCF) n=1, field bean n=2, cold-pressed rapeseed cake (CRC) n=2, full fat rapeseed (FFRS) n=1; all values were analysed or calculated from analyses, with the exception of #NorFor feed table, §Spörndly (2003), *Product sheet (Lantmännen Inc.), presented as g/kg DM, unless otherwise stated

	Feed					
	Silage[g]	Grains[h]	CCF	Field bean	CRC	FFRS
DM, %	38 (9.7)	85 (0.1)	89	87 (1.1)	90 (0.1)	92
ME[a], MJ/kg DM	10.6 (0.6)	13.9 (0.1)	15.8*	14.6 (0.7)	15.8 (0.6)	22.3
CP	135 (19.6)	123 (8.5)	338	288 (3.5)	307 (9.9)	253
sCP[b], g/kg CP	526 (68.1)	124#	108#	691#	568#	334#
Starch	nd[i]	643 (37.5)	220*	383 (87.7)	10§	10§
Crude fat	20§	33 (0.6)	159	21	177 (29.7)	456
AAT[c]	70 (2.1)	91 (1.4)	177*	95 (8.5)	89 (3.5)	74
PBV[d]	14 (18.3)	−26 (11.3)	142#	140 (10.6)	173 (5.0)	143
NDF[e]	479 (25.1)	126 (2.1)	165*	219 (12.7)	242 (0.7)	184
iNDF[f], g/kg NDF	228 (3.4)	248#	89#	25 #	509#	314#

[a] ME = metabolisable energy

[b] sCP = soluble crude protein

[c] AAT = amino acids absorbed in intestine

[d] PBV = protein balance in rumen

[e] NDF = neutral detergent fibre

[f] iNDF = indigestible NDF

[g] Fermentation characteristics (per kg DM); pH 4.2, 58-g lactic acid, 9.3-g acetic acid, 0.7-g propionic acid, 0.3-g butyric acid

[h] Same proportions of barley, oats and wheat

[i] Not determined

mixed ration, irrespective of lactation stage. Calculations on average nutrient intake were performed by conventional calculations and according to Volden (2011). The balance of net energy (NEL) was calculated as the ratio between energy in the diet and the energy required for maintenance, lactation and body condition changes. The ratio AAT/NEL was calculated as AAT available for milk production divided by the NEL requirement for lactation. When calculating the AAT from the microbes, DM intake and amount of fermented organic matter were considered. The observed intake capacity (IC), shown as fill value (FV), depended on organic matter digestibility of the roughage, NDF level and fermentation quality and both the concentrations and amounts of starch and sugar in the total diet. The predicted IC depended on milk production, cow data (breed, DIM, body weight (BW)) and cow activity (Volden 2011).

Daily milk yield was recorded and sampled individually every second week during the first 3 months of lactation and thereafter once per month. Milk composition was analysed for fat, protein, urea and somatic cell count (SCC) by infrared technology (Eurofins Steins Laboratory Inc., Jönköping, Sweden).

Body weight was recorded monthly, and the body condition score (BCS) of the cows was determined at the same time by one trained scorer, using a visual appraisal method (Edmonson et al. 1989).

Fertility of cows was determined from the number of artificial inseminations (AI) per conception, the number of days between calving and the last AI and the calving interval. All veterinary inputs were recorded continuously as a measure of cow health.

Profitability

The profitability was calculated as income from milk less cost of feed for Swedish conditions (2014 figures). Quantities of milk and feed were measured in the experiment, while data on fat- and protein-adjusted milk prices were obtained from Arla Foods (2014), the price of locally produced CRC from the supplier, and the price of other feeds from production calculations by the Swedish University of Agricultural Sciences (Agriwise 2014) and the County Administration Board of Västra Götaland (2014). The cost of silage corresponded to the long-term cost of production on farms with average grass yields and machine parks well adapted to farm size in Central Sweden, and the other feed prices were set at market price. In the basic calculation, organic milk and feed prices were used. In the sensitivity analysis, prices of conventional products and 50 % lower and higher milk and feed prices were used. Prices in SEK were converted into EUR at the exchange rate 1 SEK=0.11 EUR (April 2014).

Statistical analyses

Statistical analyses of variance on the 56 cows were performed using the General Linear Model (GLM) procedure of SAS (SAS 2010). Production data (milk yield and milk composition), BW, BCS and SCC were analysed as individual means for the first 3 months of lactation (5-90 DIM) and as individual means for later lactation up to 365 days of lactation. The statistical model included fixed effects of treatment and cow pair (which was used as a block). Procedure Univariate Normal Plot (SAS 2010) was used to assess normality of residuals. Values for SCC in milk were logarithmically transformed (natural logarithm), while no other transformations were made. Data presented are least square means with standard error of the mean. The back-transformed SCC values are presented for clarification. A value of $P<0.05$ was regarded as statistically significant.

Results

Feed intake and milk production

Cows fed SEED had 3.2 kg higher DM intake of the mixed ration than cows fed CAKE and thereby also 3.1 kg higher total DM intake (Table 2). The concentration of fat in the total diet was higher for SEED than for CAKE, especially in early lactation when it was 0.8 g higher kg DM^{-1}. The iNDF concentration was 23 and 29 g kg DM^{-1} lower in early and later lactation in the SEED diet. The net energy balance was low (−8 %) for CAKE cows in all lactation stages, whereas SEED cows had a high energy balance in both early (+3 %) and later lactation (+8 %) (Table 3). In addition, AAT/NEL was low for CAKE cows compared with the recommended level (above 15.0 for cows in lactation; Volden 2011) whereas SEED cows had AAT/NEL within the recommended level (Table 3). The observed intake capacity (shown as FV) was 10 and 5 % high in early and later

Table 2 Average feed intake in diets including either cold-pressed rapeseed cake (CAKE) or full fat rapeseed (SEED) in early (1-90 DIM[a]) and later lactation (91-365 DIM)

	CAKE		SEED	
	1-90	91-365	1-90	91-365
Grass/clover silage, kg DM	12.4	12.4	14.7	14.7
Grains[b], kg feed	4.8	4.8	5.7	5.7
CCF[c], kg feed	0.32	0.32	0.35	0.35
Minerals, kg feed	0.12	0.12	0.15	0.15
Lime, kg feed	0.1	0.1	0.1	0.1
Intake mixed ration, kg DM	*16.9*	*16.9*	*20.1*	*20.1*
Rapeseed cake, kg feed	2.4	1.5	–	–
Full fat rapeseed, kg feed	–	–	1.3	0.9
Field bean, kg feed	3.5	2.4	4.4	2.9
Total intake, kg DM	*22.1*	*20.4*	*25.2*	*23.5*
ME[d], MJ/day	267	245	310	280
CP, g/day	3735	3284	4082	3690
Crude fat, g/day	88	69	121	92
NDF[e], g/day	7735	7344	8870	8530

[a] Days in milk

[b] Same proportions of barley, oats and wheat

[c] CCF = commercial compound feed (Lantmännen Inc.)

[d] ME = metabolisable energy

[e] NDF = neutral detergent fibre

lactation in SEED cows compared with predicted intake, whereas it was 3 and 11 % low in early and later lactation in CAKE cows (Table 3). The percentage of rumen degradable CP (erdCP) was 2.5 and 2.4 % higher in early and later lactation in the CAKE diet than in the SEED diet, and the AAT from both the diet and microbes were highest for the SEED diet (Table 3).

There were no significant differences in milk yield, milk composition and milk urea, BW and BCS between the CAKE and SEED feed treatments (Table 4). Milk SCC did not differ between treatments. The mean SCC for 5-90 DIM was 57 and 35(×1,000)cells/mL in the CAKE and SEED group, respectively (lnSCC=11.0 and 10.5; SEM=0.23; P=0.156). The mean SCC for test milkings after 90 DIM was 73 and 79(×1,000)cells/mL, respectively (lnSCC=11.2 and 11.3; SEM=0.17; P=0.752).

Reproduction and health

There were 143±86 and 129±88 days from calving to last AI for cows fed the CAKE and SEED diets, respectively, and number of AI per conception was 1.54±0.72 and 1.68±0.85, respectively (n=26 and 24). The calving interval was 420±27 and 389±51 days for cows fed the CAKE and SEED diets, respectively (n=26 and 24).

There were seven recorded disease events in the CAKE group during the study (mastitis, displaced abomasum, interdigital phlegmon (2), grass tetany, other diseases (2)) and 11 events in the SEED group (mastitis (4), interdigital phlegmon, endometritis, cystic ovary, acetonaemia, gastrointestinal nematode infection, teat injury, other diseases).

Profitability

In the basic calculation with organic milk and feed prices, cows fed the CAKE diet had the highest profitability during later lactation (10.10 and 8.62 EUR per day for CAKE and SEED, respectively). The two diets had similar profitability during early lactation (11.87 and 11.86 EUR,

Table 3 Nutrient composition (mean and SD) in diets used in the experiment; in CAKE and SEED treatments, in early (1-90 DIM) or later lactation (91-365 DIM), calculated from feed analyses and feed intake, n^a=5

	1-90		91-365	
	CAKE	SEED	CAKE	SEED
ME[b], MJ/kg DM	12.1 (0.3)	12.3 (0.4)	12.0 (0.4)	11.9 (0.4)
CP, g/kg DM	169 (2.6)	162 (4.7)	161 (4.2)	154 (4.8)
Starch, g/kg DM	174 (9.3)	182 (10.3)	171 (7.4)	176 (8.0)
Crude fat, g/kg DM	4.0 (0.1)	4.8 (0.3)	3.4 (0.1)	3.9 (0.2)
AAT[c], g/MJ	6.6 (0.1)	6.4 (0.2)	6.6 (0.1)	6.5 (0.2)
PBV[d], g/kg DM	38 (3.4)	32 (4.0)	29 (3.8)	23 (4.0)
NDF[e], g/kg DM	350 (6.5)	352 (3.0)	360 (4.5)	363 (3.1)
iNDF[f], g/kg NDF	234 (26)	211 (29)	232 (28)	203 (54)
NEL-balance[g], %	92	103	92	108
AAT/NEL[h], g/MJ	12.8	15.0	13.1	16.5
Observed IC[i], FV	8.15	9.40	7.79	9.05
Predicted IC[j], FV	8.42	8.47	8.65	8.57
erdCP[k], % of CP	78.0	75.5	77.9	75.5
erdNDF[l], % of NDF	54.4	54.4	55.4	54.9
AAT[m] feed, g/day	451	574	387	494
AAT[n] microb, g/day	1419	1639	1290	1519

[a] *n* Monthly consumption

[b] ME = metabolisable energy

[c] AAT = amino acids absorbed in intestine

[d] PBV = protein balance in rumen

[e] NDF = neutral detergent fibre

[f-n] According to Volden (2011)

[f] iNDF = indigestible NDF

[g] Net energy balance, as dietary net energy in relation to the requirement

[h] Available AAT for milk protein yield in relation to energy requirement for milk yield

[i] IC = observed intake capacity, fill value

[j] IC = Norfor predicted intake capacity

[k] Efficient rumen degradable CP

[l] Efficient rumen degradable NDF

[m] Estimated g AAT from undegraded feed

[n] Estimated g AAT from microbes

respectively), when the higher intake of the mixed ration in SEED cows was compensated for by somewhat higher milk production (Table 4).

The CAKE diet resulted in the highest profitability during later lactation in all price situations studied, including an extreme case with 50 % more expensive CRC in combination with 50 % cheaper FFRS, PMR and field beans. During early lactation, the two diets showed similar results in all reasonable price situations. Similar outcome was observed when milk and feed prices for conventional production were used in calculations (data not shown).

Discussion

Both diets resulted in high milk production and similar yield and composition between the SEED and CAKE

Table 4 Number of days in milk (mean and SD), milk yield, milk composition, BCS and BW of cows fed cold-pressed rapeseed cake (CAKE) and full fat rapeseed (SEED) diets, in early (5-90; n=15) and later lactation (91-365; n=27), expressed as least square means with standard error of means (SEM)

	5-90 DIM[a]				91-365 DIM			
	CAKE	SEED	SEM	*P*	CAKE	SEED	SEM	*P*
Mean DIM	53 (23)	51 (24)			191 (76)	192 (75)		
Min-max DIM	5-89	5-89			91-363	91-350		
Milk yield (kg)	37.2	38.3	1.77	0.69	31.1	29.9	0.92	0.37
Milk fat (%)	4.17	4.12	0.15	0.79	4.09	4.20	0.08	0.35
Milk protein (%)	3.10	3.14	0.08	0.75	3.34	3.32	0.05	0.78
Milk urea (mmol/l)	4.81	4.84	0.24	0.92	4.49	4.53	0.13	0.84
BCS[b]	2.54	2.80	0.28	0.55	2.85	2.90	0.08	0.68
BW (kg)	633	624	16.6	0.72	649	655	7.97	0.61

[a] DIM: days in milk

[b] Judged on a scale from 1 to 5, where 1 is extremely lean and 5 is excessively fat (Edmonson et al. 1989), *BCS* body condition score, *BW* body weight, both measured on 10 cows in early lactation and 27 in later lactation

feed treatments. However, numerically higher milk yield was found for SEED cows in early lactation, consistent with the higher DM intake, but for CAKE cows in later lactation (after 90 DIM) at a lower DM intake, which partly explained the higher profitability for CAKE cows in later lactation. The CAKE and SEED diets were economically similar during early lactation. This contradicts findings in a study with scenario calculations, where growing rapeseed for CRC production gave low milk production per hectare and the lowest financial output (Mogensen 2004). The difference between studies is likely due not only to the unexpected higher feed intake by the SEED cows but also to different methods (experimental versus scenario), ways of calculations (e.g. milk yield per cow versus milk yield per hectare) and price levels.

Addition of oilseeds to lactating cow diets has been suggested to improve performance and milk fatty acid profile (Chilliard and Ferlay 2004; Woods and Fearon 2009). However, increased fat content in diets, including FFRS and CRC, has been shown to have only a slight influence on milk yield and composition (Mogensen 2004; Beauchemin et al. 2009; Hristov et al. 2011). CRC has been found to decrease milk protein content compared with diets with whole rapeseed (Lerch et al. 2012) or no rapeseed (Johansson and Nadeau 2006; Lerch et al. 2012), without influencing milk protein yield (Johansson and Nadeau 2006; Lerch et al. 2012). High fat content in dairy cow diets has been associated with decreased protein content in milk, probably due to increased milk yield (Wu and Huber 1994; Johansson and Nadeau 2006). The somewhat higher fat content in the SEED diet in the present study did not increase milk yield, and therefore there was probably no dilution of the milk protein (Wu and Huber 1994). Furthermore, lower disappearance of amino acids in the rumen has been shown from ground FFRS than from CRC (Homolka et al. 2007), which could have counteracted the higher fat content in the SEED diet.

Cows fed FFRS had a higher intake of the mixed ration than cows fed CRC, which was unexpected. Why this did not (especially in later lactation) result in higher milk yield from FFRS cows than from CRC cows is hard to elucidate but is similar to findings of an earlier long-term study where whole FFRS decreased milk yield compared to CRC (Lerch et al. 2012). As in our study, neither BW nor BCS were increased by the higher DM intake, suggesting inefficient use of energy from FFRS and the effects on yield could be explained by lower digestibility of the whole unprocessed FFRS (Lerch et al. 2012). Because of the high fat content in FFRS, it is recommended that this feed should be used in moderate amounts (maximum 1.5–2.0 kg per cow and day) in order to avoid affecting rumen microbes and rumen metabolism negatively (Murphy et al. 1987). The fat content in CRC is lower than in FFRS, and it is possible to use more CRC in the diet. Therefore, as the planned diets were balanced to have similar CP content, the energy content was higher in the SEED diet. Even though the protein concentration in the CAKE diet was somewhat higher compared to the SEED diet, the consumed amount of protein in the total diet was higher in the SEED cows, because of the higher DM intake by the SEED cows. Crude fat concentration in the diets consumed was higher in SEED, but not above the recommended level of 5 % (NRC 2001). In addition, the seed shell in FFRS protects lipids from ruminal metabolism (Chilliard and Ferlay 2004). Thus, even though the FFRS in the present study was coarsely ground, it may have been important for rumen function as it has been shown that the release of fat is slow from crushed rapeseed which minimises negative effects of fat on rumen metabolism (Murphy et al. 1987).

The net energy balance was somewhat low for CAKE cows (NEL balance 92 % in early and later lactation), which is normal for cows in early lactation. However, the SEED cows had higher intake than the CAKE cows and a positive net energy balance also in early lactation (NEL balance 103 and 108 % for cows in ≤90 DIM and >90 DIM, respectively). As mentioned, there were no differences in BW or BCS of the cows between treatments, which indicate that the low net energy balance in CAKE cows in later lactation was due to milk production. In fact, the CAKE cows produced 1 kg more milk per day in later lactation, in spite of the lower DM intake.

The amount of AAT available for milk production in relation to energy requirement (AAT/NEL) was also low for CAKE cows in early lactation (12.8 g/MJ compared with the recommended minimum of 15.0 g/MJ; Volden 2011), and the estimated AAT from microbes was lower for CAKE than for the SEED diet. This was most likely because of the higher feed intake of the SEED diet, giving more efficient microbial synthesis (Volden 2011). The AAT from microbes is known to have a closer AA profile to that required by dairy cows than the AAT from feeds (NRC 2001). This may be one explanation for the numerically lower milk yield from CAKE cows than from SEED cows in early lactation. However, the SEED cows also had higher feed intake in later lactation, when milk yield was numerically higher in CAKE cows, but CAKE cows in later lactation had a higher AAT/NEL balance compared with CAKE cows in early lactation. When using diets with low levels of rumen undegradable protein, it is especially important to provide a good lysine-methionine balance (ratio of 3:1 in metabolisable protein) for increased production and cow health (Liu et al. 2013). Rapeseed is a good source of methionine in particular, e.g. in comparison with soybean (Rinne et al. 2012; Maxin et al. 2013). This is of interest if soybean, containing high levels of undegradable protein, is replaced with rapeseed in organic forage-based diets.

Furthermore, ruminal microbial protein synthesis is dependent on optimal synchronisation of energy and protein supply over time, and increasing the amount of energy in the diet results in enhanced N uptake by microbes (Børsting et al. 2003). Rumen degradable feed protein can then be efficiently used to build microbial protein for production, which explains the good milk production results in the present study, even though the protein in the feeds was degraded in the rumen to a high extent. In forage-based diets, nearly two-thirds of the CP reaching the small intestine is of microbial origin (Merchen and Bourquin 1994).

There were no differences in milk urea between the two isonitrogenous (±1.0 % dietary CP concentration) diets CAKE and SEED, indicating similar N efficiency because diets with increasing CP levels decrease N efficiency (Marini and Van Amburgh 2003; Olmos Colmenero and Broderick 2006; Nadeau et al. 2007).

The udder health of the cows in the study was good, as shown by low SCC, and no significant difference was found between CAKE and SEED diets. Moreover, there were no major differences in other cow health or fertility parameters between the diets.

Cows fed CAKE had the highest profitability during later lactation (after 90 DIM), whereas CAKE and SEED were economically similar during early lactation. These conclusions apply for all price situations investigated. During early lactation, the higher intake of the mixed ration in SEED cows was economically compensated for by somewhat higher milk production. Based on the findings of the present study, by feeding CAKE instead of SEED during later lactation, a farmer with 100 lactating cows may improve profits by nearly 32,000 EUR per year in the basic price situation.

Other studies have reported a positive influence of including rapeseed in dairy cow diets on aspects such as methane emissions, local feed production, improved milk fatty acid profile and use of by-products of biodiesel production, making rapeseed a promising feed component to include in cows' diets.

Conclusions

Diets containing cold-pressed rapeseed cake and full fat rapeseed both led to high milk yield and nitrogen utilisation, probably by providing rumen degradable protein simultaneously with enough energy to build microbial protein that could be utilised for milk production. Cows fed CAKE had a lower feed intake and a numerically higher milk yield than SEED cows in later lactation, which largely explained the higher profitability for CAKE cows in later lactation. The CAKE and SEED treatments were economically similar during early lactation, when the higher feed intake by the SEED cows partly was compensated for by higher milk yield. The profitability results apply for all reasonable price situations and indicate that producing CRC can be of great interest.

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