PROJECT REPORT No. OS59

THE EFFECTS OF LONG-TERM FEEDING OF EXTRACTED RAPESEED MEAL AND WHOLE RAPESEED ON THE PHYSICAL AND FINANCIAL PERFORMANCE, HEALTH AND WELFARE OF HIGH YIELDING DAIRY COWS

OCTOBER 2002

Price: £4.25

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THE EFFECTS OF LONG-TERM FEEDING OF EXTRACTED RAPESEED MEAL AND WHOLE RAPESEED ON THE PHYSICAL AND FINANCIAL PERFORMANCE, HEALTH AND WELFARE OF HIGH YIELDING COWS

by

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This is the final report of a twenty-one month research project which started in May 2000. The work was funded by a grant of £96,024 from HGCA (project no. 2324).

Contents

Abstract

Rapeseed meal (RSM), a traditional ingredient in dairy cow diets, is a protein rich feedstuff with an energy concentration similar to that of wheat. UK dairy compound feeds contain on average 150 gkg^{-1} RSM, which has remained relatively static in recent years. This reflects the fact that many dairy farmers and their nutritional advisors remain cautious about increasing the levels of RSM in cow diets, regarding RSM as a 'cheap' protein which is thought to lead to problems such as poor fertility, lameness and reduced performance. More recently, some dairy farmers have begun to feed small amounts of whole rapeseed (WRS) as a cost-effective energy source, and as a means of reducing the concentration of butterfat or modifying the fatty acid composition of milk fat.

The aim of this project was firstly, to test the hypothesis that RSM could replace soyabean meal as the main protein source in the diet of dairy cows and secondly, to test the hypothesis that WRS could be used as an energy source for the dairy cow, without any impact on herd performance, fertility or health over the duration of a lactation.

Sixty freshly calved cows were allocated to one of three treatment diets, control, RSM (360 gkg^{-1} of the concentrate) and WRS (147 gkg^{-1} of the concentrate). Diets were formulated to be isonitrogenous and isoenergetic with grass and maize silage as the forage portion of the diet. Diets were offered as a total mixed ration (TMR) for 28 weeks, after which the cows were introduced to the grazing diet. The RSM and WRS were then offered as part of a buffer diet consisting of maize silage, molassed sugar beet feed, wheat and either RSM or WRS (3.00, 1.78, 0.86, 0.45 and 0.45 kg DM per day respectively). The control group were given the basal diet plus equal amounts (0.22 kg DM per day) of maize gluten and soyabean meal instead of the rapeseed products. After 36 weeks, the cows were removed from treatment into one group for the dry period. Dry matter intake, liveweight and condition score, milk yield and composition, the concentrations of urea, ammonia and thyroxine in the blood, fertility, lameness and general herd health were recorded throughout the study. The financial performances of the three groups were monitored throughout the lactation.

There was a significant reduction in dry matter intake for the RSM and WRS treatment compared with the control (20.8, 20.2 and 21.9 kg DM/animal/day respectively). This was not reflected in any significant effects on mean milk yield, liveweight or body condition score. Milk fat content was significantly reduced on the WRS diet and the milk fatty acid composition was altered with a reduction in the concentration of saturated fats and an increase in the concentration of monounsaturated fatty acids (MUFA). The ratio of saturates to MUFA was 2.90 and 2.15 in milk fat for the control and WRS diets respectively. There was also a significant increase in conjugated linoleic acid content of the milk fat for the WRS diet, although the highest concentration was observed, regardless of treatment, when the cows went out to grass. There was no significant effect of either rapeseed treatment on herd health (incidence of lameness or mastitis) nor was

there any effect on fertility. However, there was a numerical increase (though not significant) in the calving interval and the number of days to conception with cows fed WRS. The blood thyroxine content was significantly reduced for this treatment, which suggests that the glucosinolates in the WRS were having a mild suppressing effect on thyroid function. The overall financial performance (margin over all feed per cow) of the three treatments was £837, 855 and 877 for the control, RSM and WRS respectively. These figures were greatly affected by differences in the milk hygiene quality between the three groups (the milk from cows fed WRS achieved a premium more often than the other treatments) and the cost of the main feed ingredients (soyabean meal, maize gluten feed, megalac, RSM and WRS).

It was concluded that RSM could be included at 360 gkg^{-1} of the concentrate throughout the winter feeding period with no adverse effects on herd performance and some improvement in margins. WRS can be included at 147 gkg^{-1} of the concentrate, but should only be considered if there is a requirement to reduce milk fat or alter the fatty acid composition of the milk fat to bring about financial benefits, as there were some indications of a negative impact on herd fertility.

Summary

1. Extracted rapeseed meal (RSM) is used as a protein supplement for dairy cows, but it is considered to be of inferior quality to soyabean meal. Cracked, whole rapeseed (WRS) is used in small amounts as a source of cheap energy, and as a means of manipulating the fat content and fatty acid composition of milk. The objectives of this experiment were to determine whether home grown RSM could be used to substitute soyabean meal completely in the diets of dairy cows, and whether WRS could be included in the diet, without compromising herd performance, health, fertility or economics. The effect of WRS inclusion on the fatty acid composition of milk was also determined. Unlike many previous studies, this experiment monitored the effects of rapeseed inclusion in the diet over a whole lactation, and for the first 13 weeks of the subsequent lactation.

2. A total of 60 freshly calved cows were used (51 cows and 9 heifers). They were split into three groups of 20 cows each and fed one of three diets. For the first 28 weeks, all the cows were housed and offered their diet as a total mixed ration (TMR). For the following eight weeks, the cows were turned out to grass and offered a buffer feed. Cows in the control group (CON) were supplemented with soyabean meal and maize gluten feed. These feeds were substituted with RSM for the second group of cows (group RSM). CON and RSM were fed Megalac, a source of palm oil that has been protected from rumen digestion. The third group of cows (WRS) was supplemented with WRS in place of Megalac. All diets were formulated to have the same energy and protein contents.

3. Dry matter intakes (DMI) and milk yields were measured weekly. The cows' liveweight and condition score were estimated each month. Milk quality (fat and protein content) and the fatty acid composition of milk fat was measured monthly. The cows' foot health was estimated by determining the cows' locomotion score in early and late lactation, and by recording the number of foot lesions in each cow 12 weeks post calving. The concentration of urea, ammonia and thyroxine in the cows' blood was estimated in early, mid and late lactation. The cows' health and fertility were monitored throughout the experiment and the financial performance of each group (costs of feeds and sales of milk) were calculated for the whole lactation.

4. Feeding rapeseed reduced cows' DMI (21.9, 20.8, 20.2 kg/d for CON, RSM, WRS respectively), but this had no effect on their milk yield, liveweight or condition score.

5. Feeding WRS reduced milk fat content (40.9, 40.2, 37.5 g fat/kg milk for CON, RSM and WRS respectively), but there were no significant differences between treatments in milk protein content, or between the yields of milk fat and protein.

6. Benefits to human health have been reported by reducing the intake of lauric (C12:0), myristic (C14:0) and palmitic (C16:0) acids; by reducing the ratio of saturated : monounsaturated fatty acids

(SFA:MUFA); by reducing the ratio of C16:0:C18:0 fatty acids, by increasing the intake of conjugated C18:2 fatty acid; and by increasing the intake of C18:3(n3) cis fatty acid. Since 30% of fat intake in the UK comes from dairy products, one means of achieving these diet changes would be to alter the fatty acid composition of milk fat. If there were financial incentives for dairy farmers to produce such modified milk, one means by which they could manipulate milk fat composition would be by the inclusion of WRS in the diet. Compared with CON, the concentration of lauric, myristic and palmitic acids in the milk fat of cows fed WRS was reduced when they were fed the TMR. The values (g 100 g^{-1} fatty acids for CON and WRS respectively) were 3.6, 3.1 for lauric acid, 11.3, 10.7 for myristic acid and 30.9, 24.5 for palmitic acid. The SFA:MUFA ratio was also reduced (2.90, 2.15 respectively), as was the C16:0:C18:0 ratio (3.6, 2.2 respectively). The concentration of conjugated C18:2 fatty acid was increased (0.49, 0.60 respectively). When cows were turned out to grass there was no significant difference between treatments in the fatty acid composition of milk fat (as the proportion of WRS in the diet was then so low). Compared with when the cows were fed a TMR, grazing brought about a dramatic increase in the concentrations of conjugated C18:2 and C18:3(n3) fatty acids in the milk fat.

7. Feeding rapeseed had no effect on the concentration of blood urea and ammonia (suggesting that the metabolism of protein in the rumen had not been affected). However, feeding WRS did reduce the concentration of thyroxine in the blood, which may suggest that the WRS was affecting thyroid metabolism.

8. Although there were no significant differences between treatments in the cows' fertility, there was a tendency for cows fed rapeseed to have more days to first service, days to conception and to have a longer calving interval. In the WRS group, two of the cows were barren and three aborted (compared with one abortion in the CON group).

9. There were no significant differences between the three groups in terms of the incidences of lameness and mastitis in the cows. The somatic cell counts of cows fed WRS were lower, so that the milk from these cows attracted a premium.

10. The margins over feed costs were £837, 855 and 877 for CON, RSM and WRS respectively. Although the milk price for the WRS group was lower (because of the lower fat content of this milk), it did attract a premium (because of the low somatic cell count), and this helped increase the margin. However, these margins are very dependent on the cost of the different feedstuffs, and the particular pricing scheme that the milk buyer is operating.

11. RSM can be included in dairy cows' diets at up to 36% of the concentrate with no effect on the cows' health, performance and fertility. There may even be a benefit in terms of improved margins. WRS can be included in the diet at up to 14.7% of the concentrate, but it is recommended that it is only used if

there is a business need to reduce the milk fat content or change the fatty acid composition of the milk, as there is a risk that feeding WRS will have a negative effect on the cows' fertility.

Technical Details

Introduction

A recent MAFF survey (1995) indicated that 1.62 million tonnes (98% home grown) of oilseed rape was crushed in the UK to produce 931 000 t of RSM. The UK compounding industry used 99% of the UK produced RSM, with the ruminant sector accounting for 65% (600 000t), finisher diets for pigs 30% (280 000 t) and broiler diets 5% (40 000 t). Dairy compound feeds in the UK contain on average 15% RSM, and although this can vary from <10% to >30%, the overall level of inclusion has remained relatively static, amid concerns over the glucosinolate content of rapeseed (Fenwick *et al*, 1983). The glucosinolates are a class of sulphur-containing compounds that may reduce palatability and adversely affect thyroid function and fertility. In 1974, the first double low (00 or LG) cultivar of rapeseed was licensed in Canada and the name “canola” introduced in 1979 to describe all double low cultivars. These are cultivars that contain less than 30 $\mu molg^{-1}$ glucosinolate, as well as having a low concentration (less than 20 mg g^{-1}) erucic acid, which is another anti-nutritive factor found in rapeseed (Shahidi, 1990). Since 1991, the maximum allowable level of glucosinolate in LG-rapeseed cultivars in the EU has been 20$\mu molg^{-1}$.

With the introduction of these low glucosinolate varieties, a widespread research programme to investigate the use of LG RSM in the diets of ruminant farm livestock was undertaken. Dairy farmers and their nutritional advisors are still cautious about increasing the levels of RSM, which they regard as a 'cheap' protein, causing a variety of problems such as poor fertility, lameness and reduced performance. This perception, together with new legislation requiring a declaration of all raw materials used in compound feeds in descending order of inclusion level, has discouraged feed manufacturers from using more RSM. This is despite the absence of any scientific evidence to support the view that the new varieties of LG rapeseed cause any production problems.

In an extensive review on the use of rapeseed meal in the diet of ruminants, Hill (1991) concluded that for milk production in dairy cows, LG-RSM could be used as freely as soyabean meal and that the composition of milk was equally satisfactory from either feed. He went on to conclude that compound concentrates containing high proportions (up to 600 gkg^{-1}), of well produced LG-RSM would be accepted by dairy cows as readily as a similar feed based on soyabean meal. Emanuelson (1994) added support to these views, stating that the risk of encountering palatability problems when feeding LG RSM to adult dairy cattle was minimal, and suggested that it should be possible to feed dairy cows grain/concentrate mixes consisting of 0.2-0.3 LG-RSM without impairing feed intake or palatability.

The published data on rapeseed products in relation to health and fertility are limited, reflecting the small number of long-term studies that have been undertaken. There have been some reports in the literature (Ahlin *et al*., 1994; Ahlström, 1978 and Emanuelson *et al.*, 1987) that reproductive efficiency in young cows fed high glucosinolate (HG) RSM was lower. Among these, Lindell (1976) and Lindell and Knutson (1976) reported that when up to 1.39 kg HG-RSM was fed, the number of services per pregnancy, days from calving to conception and calving interval all increased. Similar responses were reported by Ahlström (1978) when 75 gkg^{-1} HG-RSM was fed. However, Emanuelson (1994) stated that in view of the continuous trend towards decreasing concentrations of glucosinolates in LG-RSM, all results to date indicate that it should be safe to feed LG-RSM to adult dairy cows, even as the sole protein source.

The composition of RSM can vary depending on the cultivar, region, growing conditions and processing methods. About 50% of the meal consists of crude fibre, originating from the seed coat which accounts for about 16% of the whole seed (Appelquist and Ohlson, 1972). The husk of rapeseed is difficult to remove mechanically (Bourdon, 1986) and this has made for a relatively uniform product, unlike soyabeans where the hulls can be cheaply removed or added, resulting in a range of soyabean meals that differ in fibre, energy and protein content. RSM has an energy content of 13.3 MJ/kg DM which compares favourably with wheat (13.7 MJ/kg DM) and a protein content of 400 gkg^{-1} DM (AFRC, 1993), with a good balance of essential amino acids (Laws *et al*., 1982).

Feeding whole rapeseed (WRS) is a more recent development reflecting increasing interest in WRS as a cost effective energy source, and as a means of reducing butterfat levels or modifying the fatty acid content of milk fat. WRS contains 500 gkg^{-1} oil, 200 gkg^{-1} protein and has an energy content of 21 MJ/kg DM. The oil is extremely rich in oleic acid, a mono-unsaturated fatty acid (MUFA) and also contains low concentrations of saturated fatty acids (SFA).

The COMA report on the '*Nutritional Aspects of Cardiovascular Disease*' (Department of Health, 1994) made a number of specific recommendations aimed at reducing the incidence of coronary heart disease. Prominent medical experts have since indicated that consumption of MUFA should increase while intake of SFA should fall. Typically, UK bovine milk and milk products can be regarded as major dietary sources of SFA, while contributing only small amounts of MUFA to the diet. All higher molecular weight fatty acids found in milk fat are obtained directly from the diet. Work at ADAS Bridgets, funded by MAFF (Mansbridge and Blake, 1997), and elsewhere (Murphy *et al*., 1995a,b) has shown that by feeding diets containing up to 4 kg/head/d WRS, the concentration of C18:1 in milk fat can be increased by up to 30% while dramatically reducing the concentrations of medically undesirable SFA (in particular myristic and palmitic fatty acids).

The objectives of this study were to determine the effects of long term feeding of extracted rapeseed meal or whole rapeseed to high yielding dairy cows in terms of physical and financial performance and cow health and welfare**.** Specific reference was made to milk yield and milk composition, fertility, protein and thyroid metabolism, the incidence of foot disorders and the economics of milk production.

Materials and Methods

Animals and experiment design

Three treatments were investigated, and these were fed to cows in a randomised block design. A total of 51 multiparous and 9 primiparous Holstein cows were used. Day 5 - 10 milk yield data obtained whilst in the holding group was used as a covariate for milk yield and composition data. The cows were then formed into blocks, on the basis of parity (mean 2.6, range 1 to 8) and the number of days in milk (range 10 to 24) at the start of the experiment, such that there were 20 cows per treatment. Once allocated to blocks the cows were randomly allocated to the treatment diet for a period of 36 weeks (28 weeks housed offered total mixed rations (TMR) and 8 weeks at grass with buffer feeding). Cows were housed in cubicles, which were bedded with wood shavings. Slurry was removed at frequent intervals by automatic scrapers. The experimental diets were offered as total mixed rations once daily to the treatment groups at 5% above the previous period's intake. Refusals were collected three times per week. All cows had continuous access to fresh drinking water throughout. The RSM and WRS were then offered as part of a buffer diet consisting of maize silage, molassed sugar beet feed, wheat and either RSM or WRS (3.00, 1.78, 0.86, 0.45 and 0.45 kg DM per day respectively). The control group were given the basal diet plus equal amounts (0.22 kg DM per day) of maize gluten and soyabean meal instead of the rapeseed products. Milking was done twice daily and routine daily health records were kept throughout the experimental period. After the 36 weeks the cows were returned to one group and remained at grass until calving, when they were housed, returned to their treatment groups, and offered the relevant treatment TMR for a further 13 weeks, whereupon they were removed from the study.

Treatments

The three experimental treatment diets were formulated to be isoenergetic and isonitrogenous. Each diet had a fixed premix. The grass and maize silage were sourced from ADAS Bridgets, with two different clamps used for the grass silage (clamps 19 and 18). Clamp 19 was used to week 15 when it was replaced by the grass silage from clamp 18. No adjustments were made to the TMR rations to take account of the change in forage. The concentrate feedstuffs used were sourced from Straights Direct, Pangbourne, with the exception of the WRS, which was sourced from Unitrition, Selby and had undergone a simple cracking process. The composition of the three experimental diets is given in Table 1. The straw was added to the diet after two weeks of the experiment due to the low dry matter content of the silage. The composition of the diets (presented in Table 1) was that used from weeks 5 to 29. Before this, the inclusion rate of WRS was higher, but this resulted in unsustainably low intakes by the cows fed this diet, and so the experimental diets were modified.

Table 1. *Composition of experimental diets used in the study*

	Experimental diet (g feedstuff/kg diet dry matter).		
Feedstuff	Control	Untreated RSM	Whole rapeseed
Grass silage	376	372	399
Maize silage	94	93	100
Wheat straw	20	20	20
Wheat	152	188	176
Molassed sugar beet feed	67	132	101
Rapeseed meal	43	194	20
Whole rapeseed	0	0	71
Soyabean meal	78	0	100
Maize gluten feed	167	0	0
Megalac	11	11	0
Mineral/vitamin supplement[2]	9	9	9
Limestone	3	2	5

Analyses

Total feed intake (on a fresh-weight basis) was recorded weekly for treatment groups of cows in year 1 up until the cows went out to grass. The DM content of the diets was determined three times a week and the values used to calculate total DM intake. Daily milk yield was recorded automatically for individual animals and used to calculate individual cow weekly yield. Samples of milk were bulked from two consecutive milkings in the covariate week and monthly thereafter throughout the experimental period. These samples were used in the estimation of fat and protein content by mid-infrared analysis and somatic cell count (Milkoscan, Foss Instruments, UK). For the CON and WRS treatment monthly milk samples were analysed for long chain fatty acids by gas chromatography. Cow live weight and body condition score (scale 0 to 5 according to MAFF*,* 1986a) were also recorded at calving and monthly thereafter for the year 1 experimental period and at calving and on one occasion in year 2. Locomotion score was determined in early and late lactation by assessing the gait of each cow over a 20 metre distance with score 1 being normal gait and score 5 indicating severe lameness (score 3 is slight lameness, not affecting behaviour). The feet were assessed for lesions at 12 weeks post-calving. The assessments were made in three areas of the white line region (1, 2 and 3 in Diagram 1 below) and two areas of the sole (4 and 5) and the severity of the lesion was described by a score of 1 to 7. The incidence of mastitis and lameness were recorded throughout the lactation. For 12 weeks post-calving milk samples taken twice per week were preserved with Lactabs and analysed for milk progesterone at Ridgeway Science Ltd, Alvington, Gloucestershire. Eight cows per treatment were selected for blood sampling in early, mid and late lactation. On each occasion two sets of 10 ml of blood were collected from the caudal vein. One sample was collected into a purple top vacutainer (containing EDTA) and was analysed by the Royal Veterinary College, North Mimms, Hertfordshire, for urea and ammonia concentrations. The other sample was collected into red top vacutainers (plain) and analysed by VLA, Shrewsbury, for thyroxine concentrations.

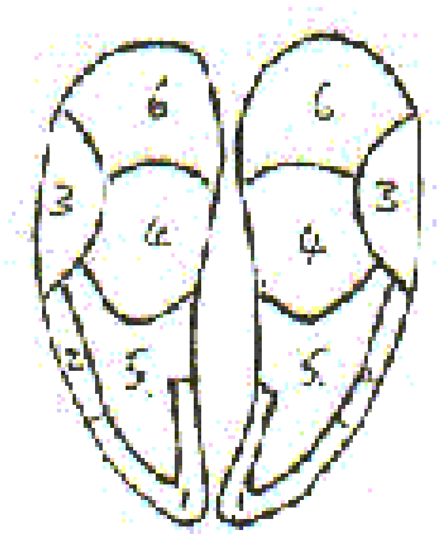


Diagram 1. Plantar aspect of the hoof, describing the white line and sole regions assessed for lesions.

A representative sample of the grass and maize silage used in the experiment was taken each week. These samples were bulked and stored frozen at approximately -20^{o}C pending analysis. The grass and maize silage were analysed for dry matter (DM), pH, total and ammonia nitrogen (N), starch (maize silage only), neutral detergent fibre (NDF), total ash (by NIRS) and short chain fatty acids (SCFA) by gas chromatography. The organic matter digestibility (OMD) of the grass and maize silages was predicted by near infrared spectroscopy (NIRS, Offer *et al.,* 1996) and was used to estimate the metabolisable energy (ME) content of the grass silage (Barber *et al.,* 1990). Silage DM was corrected (CDM) using measured concentrations of SCFA and the proportion of SCFA lost during oven drying was estimated according to Porter *et al.* (1984). The other feedstuffs used in the experiment (given in Table 1) were stored frozen below -12^{o}C pending analysis. These feedstuffs were analysed for DM, total N, acid ether extract (AEE), total ash and neutral cellulase gammanase digestibility (NCGD) according to the methods of MAFF (1986b). In addition the test protein feedstuffs (rapeseed meal and heat treated rapeseed meal) were analysed for glucosinolate content. Metabolisable energy content of these feedstuffs was determined according to MAFF (1993). The feed samples were analysed for long chain fatty acids by gas chromatography.

Statistical analysis

Milk yield and composition, feed intake, live weight and body condition score data recorded during the covariate week were used as covariates in the subsequent statistical analysis. The effect of treatment was measured using repeated measures analysis of variance. Body condition and locomotion score data were analysed using Kruskal-Wallis analysis of variance by ranks.

Results

Feed analysis

The mean chemical composition of the grass and maize silages and other feedstuffs used in the experiment are presented in Table 2. The long chain fatty acid composition of the feeds is presented in Table 3. The grass silages had low DM contents and low pH values, and were well fermented with high lactic acid contents (109 and 99 g/kg DM for Clamps 19 and 18 respectively). The grass silage from the two clamps differed only in their N and NDF contents with Clamp 18 having lower and higher N and NDF respectively than Clamp 19. The grass silages had predicted ME values of 11.8 and 11.5 MJ/kg CDM for Clamp 19 and 18 respectively. The maize silage was of good quality with a starch content of 284 g/kg DM.

The oil and NCGD contents were higher and the nitrogen content lower in WRS compared with RSM. The chemical compositions of the other feedstuffs were within the range of values expected. The long chain fatty acid composition of the grass silage consisted primarily of C18:3 (n3) cis, C18:2 (n6) cis and C16:0. The saturated to unsaturated fatty acid ratio was 0.21. The oil in WRS consisted predominantly of C18:1 (n9) cis, and the saturated to unsaturated fatty acid ratio was 0.065. The whole rapeseed and grass silage were the only feeds which contained conjugated linoleic acid (CLA, 70 and 10 g kg^{-1} DM respectively). The extracted rapeseed meal, although lower in oil content, had a similar fatty acid composition to the oil in the whole rapeseed. The maize gluten feed, molassed sugar beet feed and wheat were all high in C18:2 (n6) cis and their saturated to unsaturated fatty acid ratios were 0.22, 0.42 and 0.24 respectively.

Table 2. *Chemical composition of the feeds used in the experiment (as g/kg dry matter unless stated otherwise).*

Determination	Feedstuff								
	Grass silage clamp 19	Grass silage clamp 18	Maize silage	Cracked rape	Extracted rapeseed meal	Soyabean meal	Maize gluten feed	Sugar beet feed	Ground wheat
Dry matter (g/kg freshweight)	228	228	322	915	882	874	889	876	888
Total ash	94	88	37	41	77	60	70	101	16
Total nitrogen	30	26	16	36	62	84	41	17	22
Acid ether extract	ND	ND	ND	440	39	32	49	15	27
NCGD[1]	ND	ND	ND	878	750	933	762	865	936
Estimated ME (MJ/kg DM)[2]				23.3	11.5	13.9	11.9	12.5	13.8
pH	4.0	3.8	3.7						
Ammonia-nitrogen (g/kg total nitrogen)	106	108	160						
Neutral detergent fibre	450	493	399						
Estimated metabolisable energy (MJ/kg DM)	11.8	11.5	11.3						
Estimated fermentable ME (MJ/kg DM)	8.3	8.3	ND						
Acetic acid	34	28	ND						
Propionic acid	ND	ND	ND						
n-Butyric acid	1	<1	ND						
Lactic acid	109	99	ND						

[1]NCGD, Neutral cellulase gammanase digestible organic matter content [2] According to MAFF (1993)

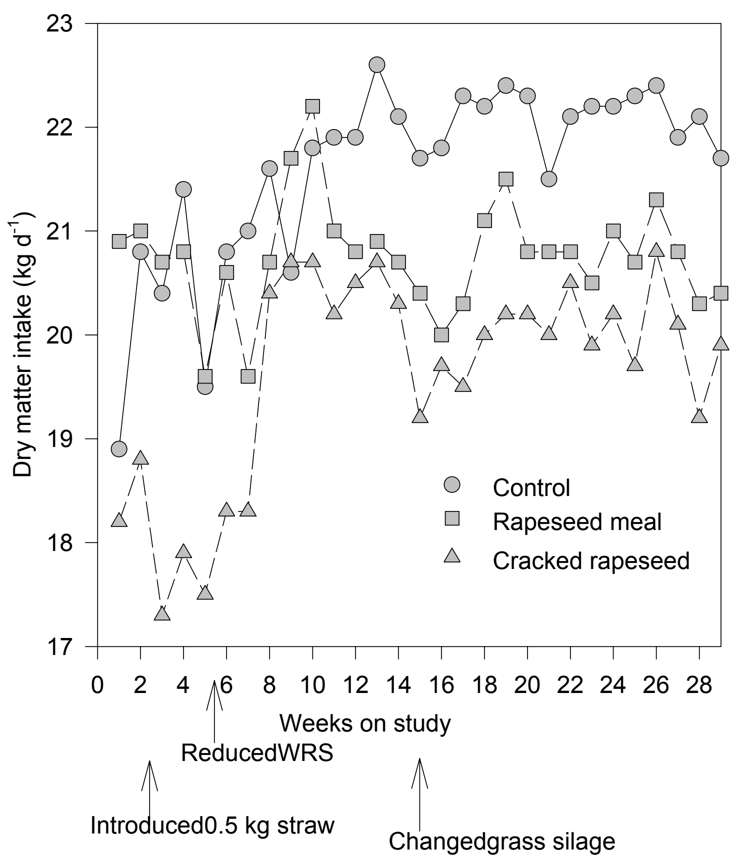
Table 3. *Long chain fatty acid composition of the feeds used in the experiment (g/kg total fatty acids).*

Determination	Feedstuff						
	Grass silage	Cracked rape	Extracted rapeseed meal	Soyabean meal	Maize gluten feed	Sugar beet feed	Ground wheat
C4:0	<10	<10	<10	<10	<10	<10	<10
C5:0	<10	<10	<10	<10	<10	<10	<10
C6:0	<10	<10	<10	<10	<10	<10	<10
C7:0	<10	<10	<10	<10	<10	<10	<10
C8:0	<10	<10	<10	<10	<10	10	<10
C9:0	<10	<10	<10	<10	<10	<10	<10
C10:0	<10	<10	<10	<10	<10	<10	<10
C11:0	<10	<10	<10	<10	<10	<10	<10
C12:0	<10	<10	<10	<10	<10	<10	<10
C13:0	<10	<10	<10	<10	<10	<10	<10
C14:0	10	<10	<10	<10	<10	20	<10
C15:0	<10	<10	<10	<10	<10	<10	<10
C16:0	120	40	80	140	140	220	170
C17:0	<10	<10	<10	<10	<10	<10	<10
C18:0	20	20	10	40	30	30	10
C18:1(n9)cis	70	590	410	150	220	110	110
C18:1(n7)cis	<10	20	80	10	10	10	<10
C18:2(n6)cis	160	220	280	530	530	460	590
C18:3(n3)cis	460	20	80	80	30	80	50
C18:2conj	10	70	<10	<10	<10	<10	<10
Others	150	20	60	50	40	60	70

Dry matter intake and cow performance

The effects of treatment on DM intake, cow liveweight and condition score and cow performance are summarised in Table 4. There was a significant (P<0.001) effect of the replacement of soyabean meal and maize gluten feed with either rapeseed meal or whole cracked rapeseed on overall total DM intake. Regardless of type, the inclusion of rapeseed reduced DM intake when measured from week five to week 29 (this was after the level of cracked rapeseed was reduced). The mean DM intakes were 20.8, 20.0 and 21.9 kg DM/animal/day for RSM, WRS and control treatments respectively. The control group of cows tended to be heavier throughout the trial compared with the rapeseed treatments. There was no significant effect of treatment on condition score.

Figure 1 Effect of week and treatment on dry matter intake



There was a significant (P<0.001) effect of time on dry matter intake between weeks 5 and 29 of the experiment (Figure 1). This was the time that cows were fed the total mixed ration. There was also a significant effect of time on both liveweight (Figure 2) and condition score (Figure 3). As expected liveweight declined for five weeks post calving regardless of treatment although the weight loss was most severe for the cracked rapeseed treatment as a result of the low DMI on that treatment. After five weeks liveweight on all treatments increased over the remainder of the lactation. Notably liveweight for the cracked rapeseed treatment rapidly increased to a level in line with the other treatments once DMI was restored to an acceptable level. Condition score declined in early lactation and there was then a gradual improvement over the duration of the experiment from week 12 onwards. There was a slight decline in condition score for all treatments after the grazing ration was introduced.

Figure 2. Effect of time and treatment on liveweight

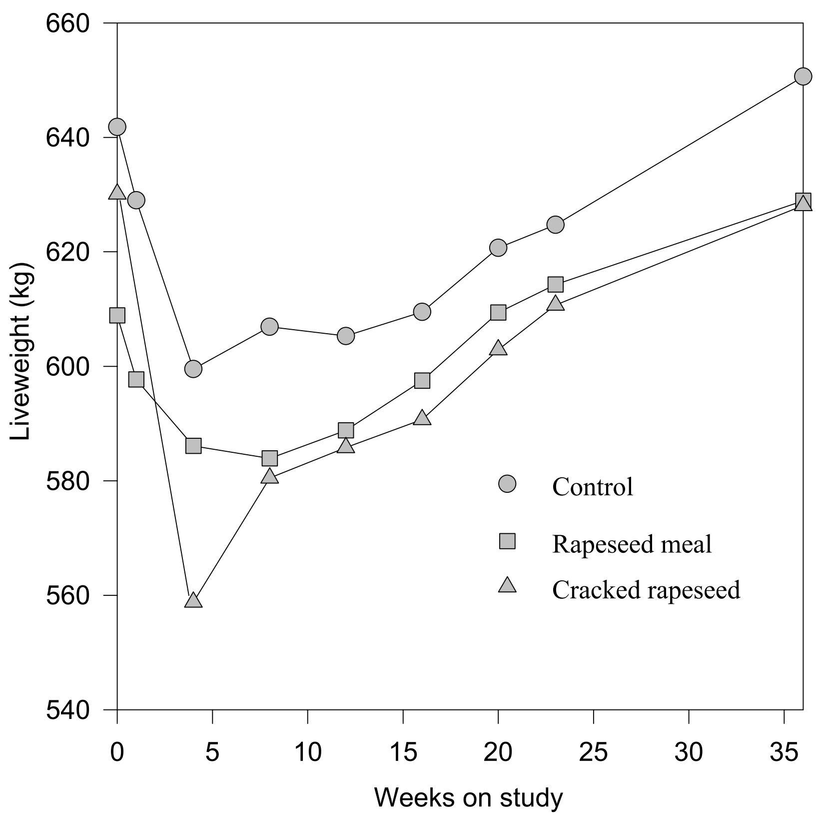
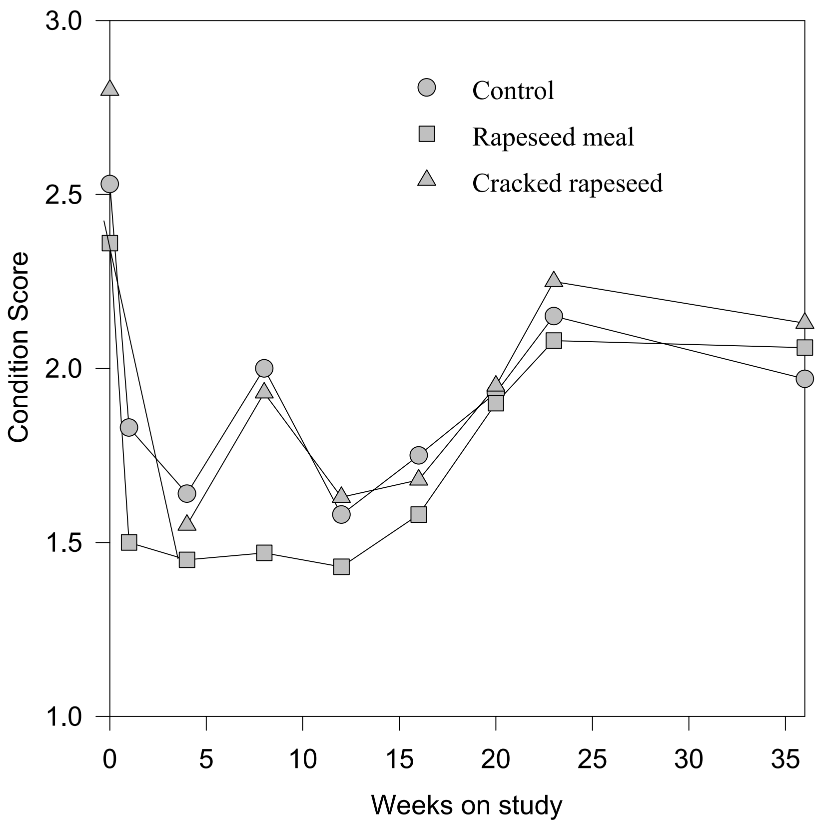


Figure 3. Effect of time and treatment on condition score



Overall, milk yield tended to be increased by inclusion of the cracked rapeseed, but this did not reach statistical significance ($P>0.05$). There was a significant effect of time ($P<0.001$) on milk yield (Figure 4), whereby daily milk yield declined for the first eight weeks of the study and then increased for four weeks, before resuming a gradual decline. The decline in milk yield was more rapid after about week 26, probably due to a combination of going out to grass, the effect of pregnancy on lactation and the stage of lactation.

Table 4. *Effect of diet on mean dry matter intake, milk yield, milk composition and yield of milk constituents*

Parameter	Experimental diet			Significance		
	Control	RSM	WRS	Time	Treatment	Time x treatment
DM intake (kg/d)	21.9	20.8	20.0	0.49***	0.16***	NS
Mean liveweight (kg)	613	598	594	2.1***	NS	NS
Condition score	1.90	1.75	1.93	0.218***	NS	NS
Milk yield (kg/d)	33.8	33.9	34.2	0.32***	NS	NS
Milk composition						
Fat (g/kg)	40.9	40.2	37.5	0.65***	1.41*	NS
Protein (g/kg)	32.4	32.6	31.4	0.17***	NS	NS
Yield of milk constituents (kg/d)						
Fat	1.29	1.27	1.22	0.026***	NS	NS
Protein	1.03	1.04	1.03	0.014***	NS	0.042*
Concentration of constituents in blood						
Urea (mmol/l)	6.05	5.96	6.20	0.328*	NS	0.568*
Ammonia (µmol/l)	102	105	97	14.8***	NS	NS
Thyroxine (nmol/l)	54.6	56.1	46.9	NS	3.01**	NS

NS, not significant; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

There was a significant effect ($P<0.05$) of treatment on the milk fat content with the cracked rapeseed treatment lowering the milk fat content over both the TMR period and the whole lactation. However, there was no significant effect of treatment on milk fat yield. There was no significant effect of treatment on milk protein content or yield. Time had a significant ($P<0.001$) effect for all milk composition parameters. There was a significant time x treatment interaction for the yield of milk protein. These effects are illustrated in Figures 5, 6, 7, and 8.

Figure 4. Effect of time and treatment on milk yield

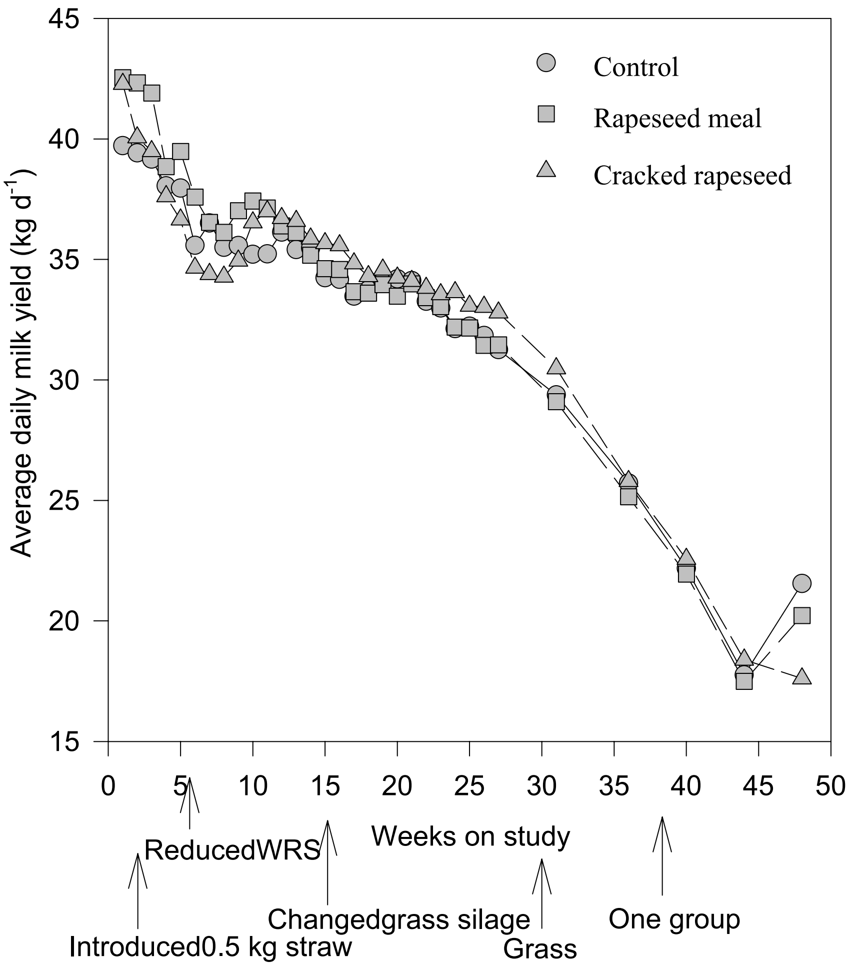


Figure 5. Effect of time and treatment on the milk fat content

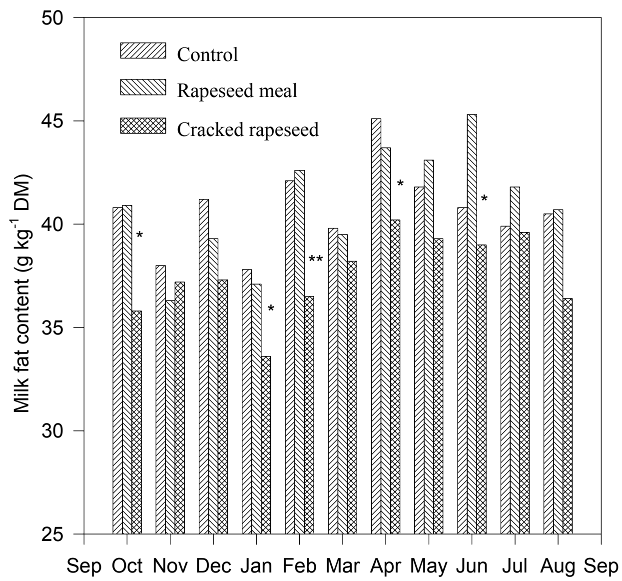


Figure 6. Effect of time and treatment on milk protein content

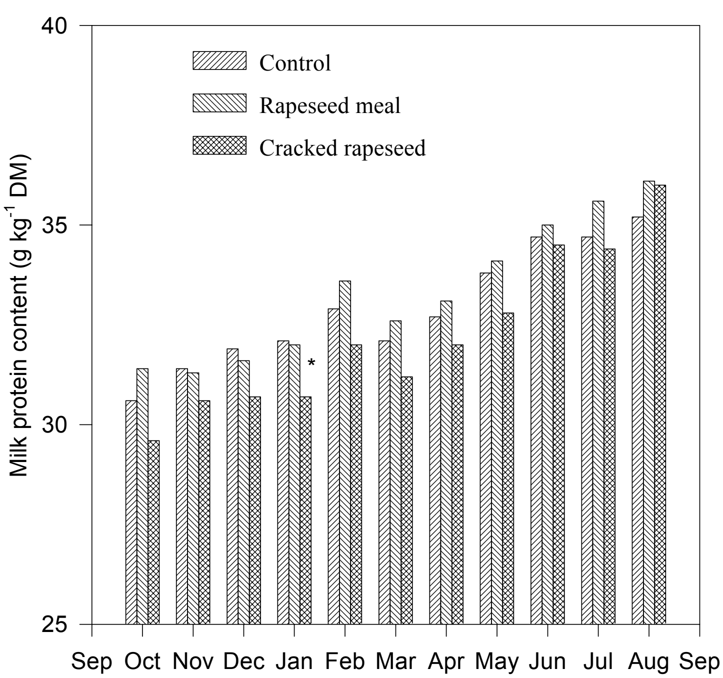


Figure 7. Effect of time and treatment on the milk fat yield

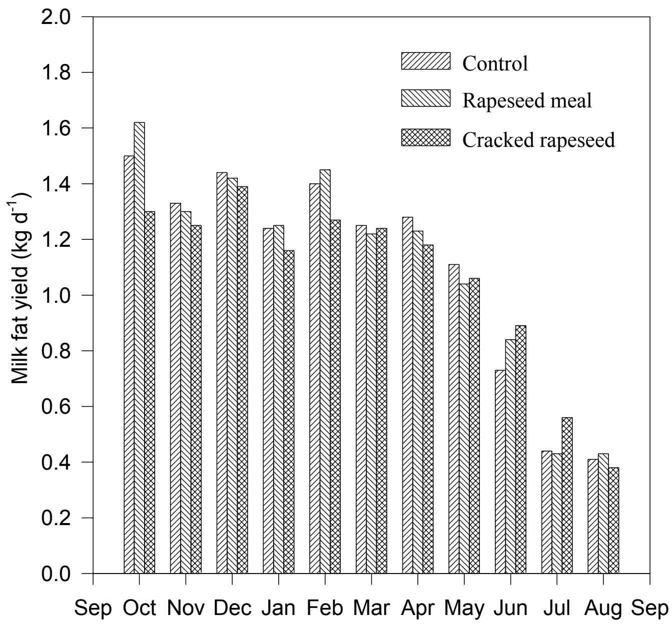
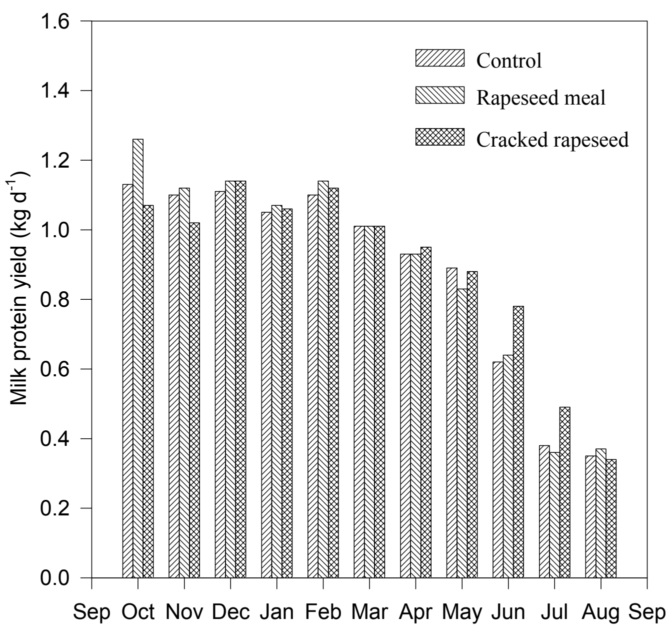


Figure 8. Effect of time and treatment on milk protein yield



Blood urea, ammonia and thyroxine were measured in early, mid and late lactation. There was no effect of treatment on blood urea and ammonia concentration, but there was a significant effect of time (figures 9 and 10) and for blood urea there was a significant interaction for time x treatment. For blood urea there was a significant reduction in concentration with time, except for the rapeseed meal treatment, which resulted in the concentration of blood urea beginning to rise again when the cows were put onto the grazing ration. For all treatments the blood ammonia concentration declined once the grazing ration was introduced.

Blood thyroxine concentration was measured to give an indication of any effects of rapeseed on thyroid function. Blood thyroxine concentration was significantly lower for the cracked rapeseed treatment and there was no effect of time (Figure 11).

Figure 9. The effect of treatment and time on blood urea concentration

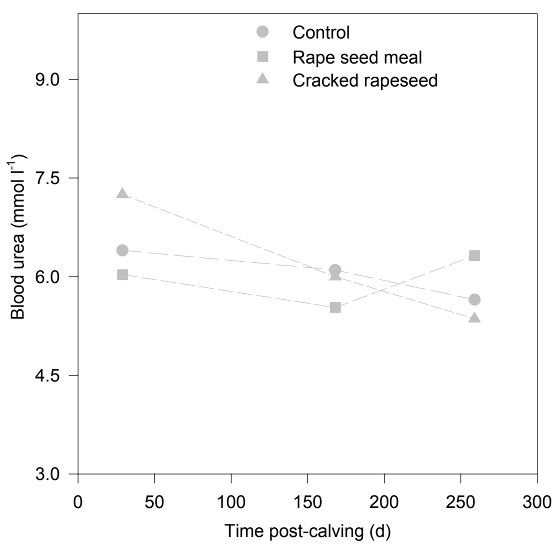


Figure 10. The effect of treatment and time on blood ammonia concentration

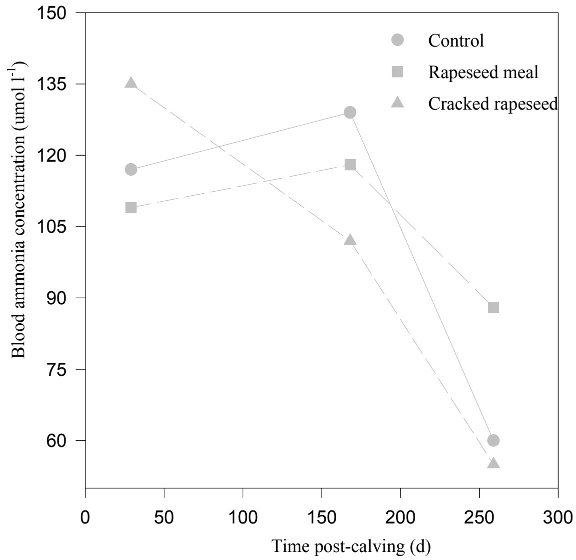
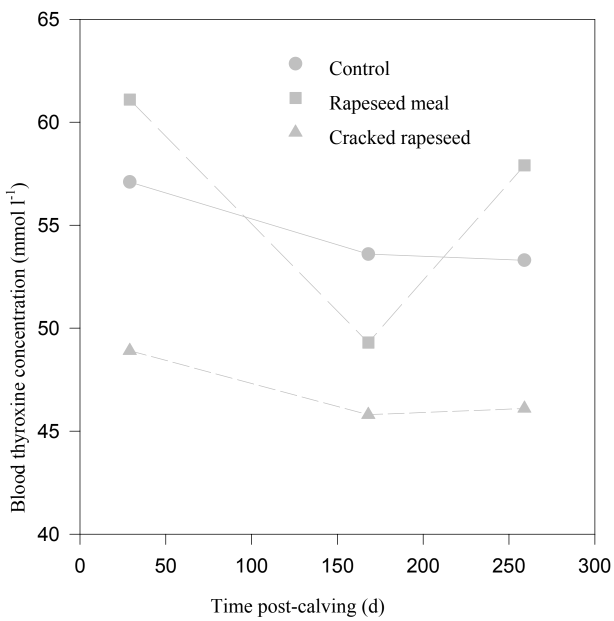


Figure 11. The effect of treatment and time on blood thyroxine concentration



Milk fatty acid composition for the control and cracked rapeseed treatments

Table 5 shows the fatty acid composition of the milk fat. There was a significant effect of treatment on all the fatty acids reported. Feeding cracked rapeseed significantly reduced the

C10 to C16 fatty acids (including C14:0 and C16:0), and increased the C18:0 content of the milk fat compared with the control. The cracked rapeseed diet significantly increased C18:1 (n9) cis and conjugated C18:2 compared with the control by 21 and 22% respectively. There was a significant effect of time for all the saturated fatty acids with the exception of C16:0 and a significant effect of time for the C18:1 (n9) and C18:2 conjugated unsaturated fatty acids. Figure 12 shows the effect of treatment and time on the saturated fatty acids (C10 to C16:0 and C18:0). Throughout the TMR feeding period, the concentration of C10:0 to C16:0 fatty acids was greater in milk fat from the control cows compared with those fed WRS. In contrast, the concentration of C18:0 was slightly greater from cows fed WRS. While being fed the TMR, there was little change in the concentrations of these fatty acids with time. Once the cows were put out to graze, the concentration of C10:0-C16:0 fatty acids in the milk from the control cows decreased to the value previously observed with the cows fed WRS. There was a concomitant increase in the concentration of C18:0, and this was also to the concentration previously observed with WRS. When at grass the amount of WRS that was fed to cows in the WRS group was reduced, and there was no significant difference in the concentration of the fatty acids in the milk from cows in the control and WRS groups.

Table 5. *Effect of diet on milk fatty acid composition (g 100g^{-1} total fatty acid)*

	Experimental diet		Significance	
Fatty acid	Control	WRS	Time	Treatment
C4:0	5.1	5.3	0.18***	NS
C6:0	2.3	2.3	0.06*	NS
C10:0	3.0	2.8	0.07*	0.04***
C12:0	3.6	3.1	0.07*	0.04***
C14:0	11.3	10.7	0.12***	0.07***
C16:0	30.9	24.5	NS	0.37***
C18:0	8.5	10.9	0.40*	0.23***
C18:1 (n7) trans	1.2	1.8	NS	0.13**
C18:1 (n9) cis	16.9	20.5	0.49**	0.28***
C18:2 (n6) cis	2.0	1.9	NS	0.03*
C18:3 (n3) cis	0.6	0.7	NS	0.02*
C18:2 conjugated	0.49	0.60	0.019***	0.011***
Other	2.5	3.1	0.12*	0.07***

NS, not significant; * P<0.05; ** P<0.01; *** P<0.001;

The effect of time and treatment on the concentrations in milk fat of t,11 C18:1 n-7 (vaccenic acid) and C18:2 conjugated fatty acid are illustrated in Figure 13. The concentration of vaccenic acid was consistently higher with cracked rapeseed compared with the control. When cows were fed the cracked rapeseed, there was a significant increase in vaccenic acid between weeks 5 and 26, but this was not observed with the control diet. There was a significant increase in the concentration of vaccenic acid in the milk fat when the cows were offered the grazing rations, and this was observed with both groups of cows. The cracked rapeseed significantly increased the concentration of C18:2 conjugated fatty acid in the milk fat compared with the control. There was a significant effect of time with an overall reduction in concentration though the period when this occurred corresponded to a change in the grass silage used. After an initial drop in concentration of C18:2 conjugated at turn-out there was a significant increase for both diets.

During the TMR phase of the experiment there was no significant effect of time on C18:3 (n3) cis fatty acid content in milk (Figure 14). At turnout there was a significant increase in C18:3 (n3) fatty acid content for both treatments. For C18:1 (n9) cis the cracked rapeseed treatment was consistently higher than the control when the TMR diets were fed. With both treatments the concentration of this fatty acid declined to week 14 and then increased again to the point of turnout (Figure 15). After turnout there was no difference between the treatments in the concentration of C18:1 (n9) in the milk fat, which was then similar to the concentrations that had been observed with cracked rapeseed when the TMR diets were fed. The cracked rapeseed treatment had consistently lower C18:2 (n6) cis concentration in the milk fat than the control and this did not significantly alter with time (Figure 16). There was a significant decline in the concentration of C18:2 (n6) cis in the milk fat regardless of treatment once the cows were offered the grazing ration.

Figure 12 The effects of treatment and weeks on the study on saturated fats (C10, C12, C14 and C16:0; and C18:0)

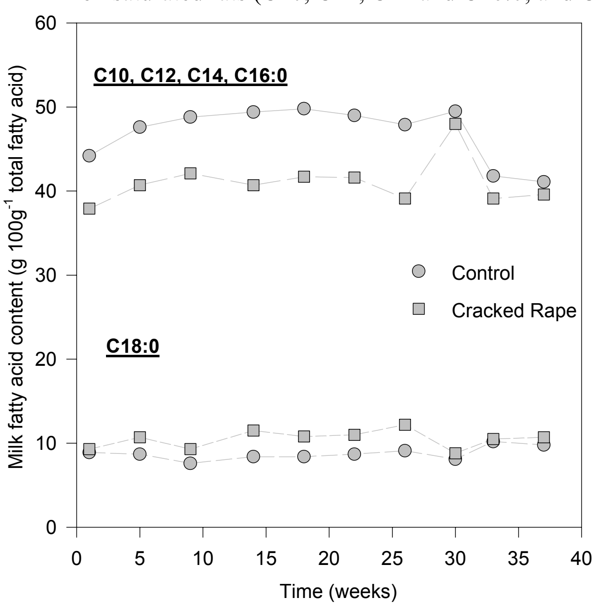


Figure 13. The effect of treatment and weeks on the study on t11, C18:1 n-7 cis and conjugated C18:2.

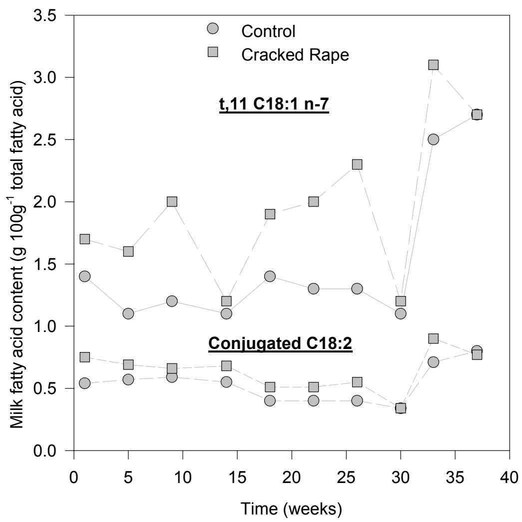


Figure 14. The effects of treatment and weeks on the study on C18:3 (n3) cis.

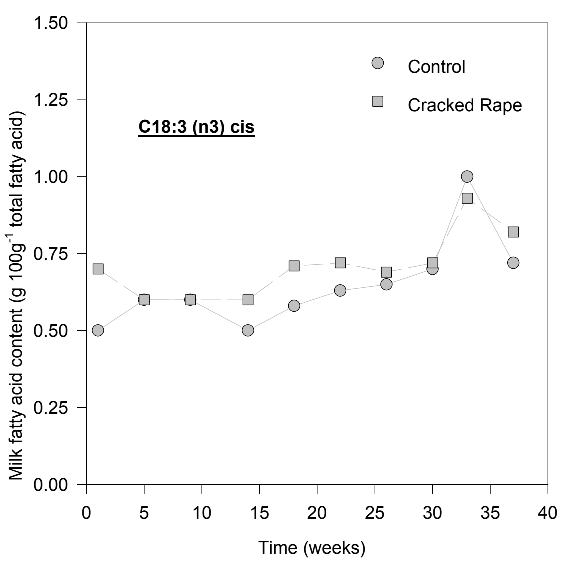


Figure 15. The effects of treatment and weeks on the study on C18:1 (n9) cis.

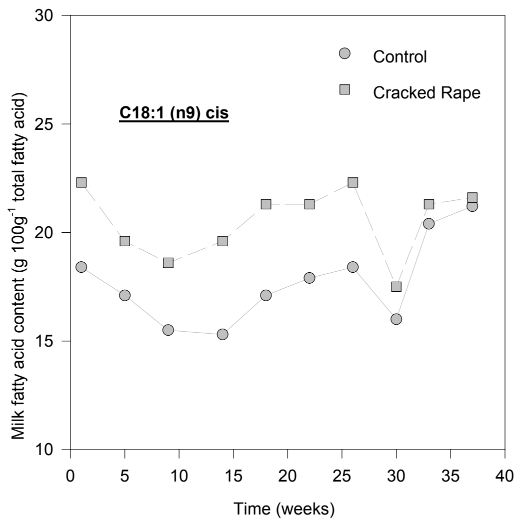
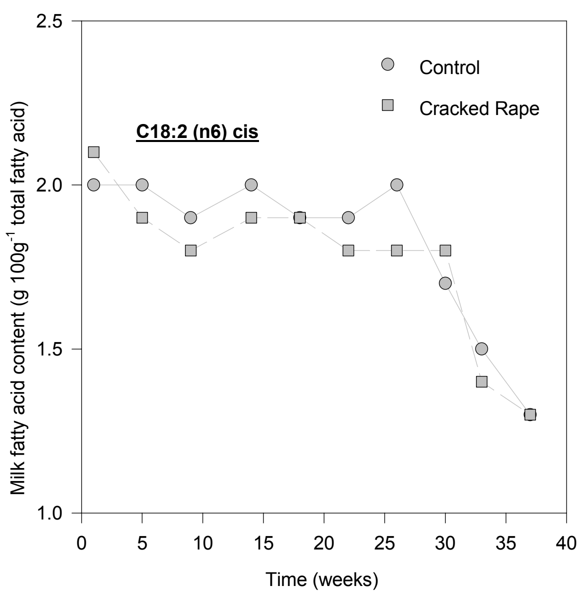


Figure 16. The effects of treatment and weeks on the study on C18:2 (n6) cis.



General health and fertility of the cows throughout the lactation

Fertility

There was no significant effect of treatment on fertility as determined by days to first service, days to conception and calving index (Table 6). There was however a trend towards increased number of days to conception and hence a longer calving index for the rapeseed treatments compared with the control. In addition, for the rapeseed meal and cracked rapeseed treatments, there were two and three cows respectively which were not in calf by the end of the 115 d breeding period. For the rapeseed meal treatment both cows were subsequently confirmed in calf at 95 and 156 days post-calving, whilst for the cracked rapeseed treatment two of the cows were barren and the third cow was confirmed in calf at 170 days. The control group had one cow that aborted 82 d after the last service and the cracked rapeseed treatment group had three cows that aborted 90, 126 and 203 d after the last service. These cows maintained high milk yields throughout their lactation and were in poor body condition.

Table 6 *Effect of diet on cow fertility and general health.*

	Experimental diet			Significance
Parameter	Control	Rapeseed meal	Cracked rapeseed	Treatment
Days to first service	55	58	58	NS
Days to conception	78	86	89	NS
Calving index (d)	360	368	371	NS
Number of conception to 1st service	8	10	7	NS
Locomotion score				
November	2.1	1.9	2.0	NS
June	2.2	1.9	1.9	NS
Lesion score at 12 weeks post-calving				
White line haemorrhage area 1	0.60	0.05	1.10	NS
White line haemorrhage area 2	1.10	0.65	0.85	NS
White line haemorrhage area 3	4.95	6.15	3.95	NS
Sole haemorrhage area 4	5.60	4.55	4.65	NS
Total score	14.7	13.8	12.8	NS

NS, not significant.

General health

There was no significant effect of treatment on general health of the cows in terms of foot health and the incidence of mastitis (Table 6 and 7). There was a tendency for foot health to be slightly improved for the rapeseed treatments.

Table 7. *The effect of diet on the incidence of lameness and mastitis.*

Parameter	Experimental diet			Significance
	Control	Rapeseed meal	Cracked Rapeseed	Treatment
Incidence of lameness (cases/cow)				NS
None	13	19	16	
One	7	1	3	
Two	0	0	1	
Incidence of mastitis (cases/cow)				NS
None	16	16	14	
One	4	3	4	
Two	0	1	1	
Three	0	0	1	

NS, not significant

Financial performance

The effect of treatment on the economics of milk production throughout the lactation is shown in Table 8. The diet cost was calculated using the actual cost of the components as purchased, with soyabean meal, maize gluten feed, megalac, rapeseed meal and cracked rapeseed purchased at £140, 76, 345, 90 and 212 per tonne respectively. The diet cost (p/d) was lowest for the rapeseed meal diet, but due to the increased milk output for the cracked rapeseed treatment and the higher milk price, the margin (£/cow) was greatest for this treatment. The milk price for the cracked rapeseed was lower than the other treatments in terms of payment for milk fat and protein, but was consistently higher in terms of the cell count banding payment. The Control and rapeseed meal treatment consistently failed to reach the standards to receive the band 1 payment (< 150,000 somatic cell count) which at 0.3 p/l had a significant impact on the total milk price received.

Table 8. *The effect of treatment on the economics of milk production*

	Experimental diet		
	Control	Rapeseed meal	Cracked rapeseed
Diet cost p/d	189	183	187
Total milk yield (l)	8552	8634	8814
Milk yield l/cow/d	27.0	26.6	26.1
Milk value p/l	17.38	17.49	17.56
Feed costs p/l	4.31	4.14	4.21
Margin p/l	9.53	9.82	9.86
Margin £/cow	837	855	877

Discussion

In this study rapeseed meal was included at 36% of the concentrate component to maintain digestible undegraded protein (DUP) supply when replacing soyabean meal and maize gluten feed. This inclusion level is twice that recorded for UK dairy compound feeds (15%, MAFF Statistics, 1995). At this level, feeding the untreated rapeseed meal as the major protein source produced the same milk yield and quality as a diet based on soyabean meal and maize gluten feed. This agrees with the results of Garnsworthy (1997) and Moss *et al*. (2000) who replaced fishmeal and soyabean meal with rumen protected rapeseed meal and showed no adverse effect on production. In addition, the concentration of urea and ammonia in the blood was not affected, suggesting that urea excretion was not elevated for the rapeseed meal treatment.

In contrast the cracked rapeseed was included at 14.7% of the concentrate component replacing megalac as a source of rumen protected fat and the maize gluten feed. Usage of whole rape on farm is relatively small due to difficulties in cracking or crushing the rape, and is rarely used in ruminant compound feeds. At this level of feeding the cracked rapeseed as the major energy source produced the same milk yield as the control, but with a significant decline in milk fat content. Dry matter intake was also significantly reduced for the cracked rapeseed treatment, though there was no significant effect on the liveweight or the condition score of these cows. Givens *et al.* (unpublished results) fed cows in mid-lactation a concentrate that consisted of 32% cracked rapeseed. They recorded, over an eight week period, a significant reduction in both milk yield and dry matter intake (3.6 and 1.7 kg reduction respectively compared with the control). Milk fat content was also significantly reduced (from 42.1 to 33.5 g/kg milk fat). As was observed in the current study, Givens *et al*. (unpublished results) showed that milk protein content was unaffected by the addition of cracked rapeseed to the diet. In this study, in early lactation when the level of supplementation of cracked rapeseed was 19.0% of the concentrate component, there was a significant decline in dry matter intake and liveweight that was believed to be unsustainable. When the level of inclusion of cracked rapeseed was reduced to 14.7% of the concentrate dry matter intake was improved.

The addition of cracked rapeseed to the diet significantly reduced the milk fat content, but did not affect the milk fat yield. The increase in total C18 fatty acids in milk fat (control, 31.6; cracked rapeseed 39.1 g $100g^{-1}$ milk fat) was very similar to the values obtained by Murphy *et al*. (1987) when feeding 0 and 1 kg cow^{-1} d^{-1} of cracked rapeseed. In the present work approximately 0 and 1.75 kg cow^{-1} d^{-1} were fed. Typically total milk fatty acids consist of between 200 and 250 g kg^{-1} of the MUFA oleic acid (C18:1 n-9) (Chilliard *et al*., 2000).

Whilst some is produced from stearic acid (C18:0) by desaturation in the mammary gland (Bickerstaffe and Annison, 1968), other work (e.g. Murphy *et al*., 1990; 1995 b) has shown that the concentration of C18:1 in milk fat can be increased by up to 30%, as a result of direct incorporation from the diet, by feeding diets containing whole cracked rapeseed. Further increases may be possible if whole cracked rapeseed can be protected from rumen biohydrogenation.

In the present study, an increased dietary supply of C18:1(n-9), the predominant fatty acid in rape oil, produced an increase in this fatty acid in the milk fat from 16.9 (control) to 20.5 g $100g^{-1}$ of total fatty acids for the cracked rapeseed. Although this was a significant increase in C18:1 (n9) concentration, it is noteworthy that the gross apparent efficiency of capture of dietary fatty acids in milk fat was low (11.9% for the cracked rapeseed diet). The cracked rapeseed diet represented a supplementation of 625 g d^{-1} of rapeseed oil to the cow and the gross apparent efficiency of capture of dietary C18:1(n9) was only slightly higher than that (10.6%) found by Chilliard and Doreau (1991). Givens *et al*. (unpublished results) produced a linear increase in C18:1(n9) fatty acid in milk fat from 181 (control) to almost 400 g kg^{-1} of total fatty acids at the highest level of whole rape inclusion (1.97 kg rape oil cow^{-1} d^{-1}). Although this was a very substantial increase in C18:1(n-9) concentration, the gross apparent efficiency of capture of dietary fatty acids in milk fat was low (7.3 % for a diet supplying 1.21 kg rape oil cow^{-1} d^{-1}), and only -0.47% for a diet supplying 1.97 kg rape oil cow^{-1} d^{-1} in which the yield of milk fat was low. It therefore appears that the efficiency of transfer of dietary C18:1(n9) to milk fat is significantly reduced at high levels of dietary supplementation of rape oil from cracked rapeseed.

It is recognised that fatty acids with a chain length of 16 or more carbon atoms are potent inhibitors of mammary fatty acid synthesis (Chilliard *et al*., 2000). This is mainly as a direct inhibitory effect on acetyl-Co A carboxylase, the enzyme responsible for the initial incorporation of acetate during fatty acid synthesis. This effect is implied in the model of Hermansen (1994), developed to predict the fatty acid composition of milk fat from dietary fatty acids and is borne out in the present study where milk fat concentrations of essentially all fatty acids from C4:0 to C17:1 were reduced significantly as a result of rapeseed supplementation. This effect may have been exacerbated by a reduced supply of acetate and 3-hydroxybutyrate from the rumen due to the associated reduction in dry matter, and hence energy, intake.

The key strategy of substituting mono-unsaturated fatty acids (MUFA) for saturates (Williams, 2000) was achieved by supplementing with cracked rapeseed. The ratio of saturates to MUFA decreased from 2.90 in milk fat from the control diet to 2.15 in milk fat from the cracked rapeseed diet. In particular, it is now clear that it is mainly lauric, myristic and palmitic fatty acids that are responsible for increasing total and LDL cholesterol concentrations in human plasma. All three fatty acids were substantially reduced in milk fat from rapeseed supplemented diets. A decrease in the C16:0 to C18:0 ratio in milk fat has also been shown to be beneficial to human health (Ney, 1991) and between the control and the cracked rapeseed diets this ratio was reduced from 3.6 to 2.2. Another goal for human health, which would also increase the spreadability of butter, would be to decrease the C18:0 to C18:1 (n-9) ratio (Chilliard *et al*., 2000) but this did not occur in this study.

It is noteworthy that the cracked rapeseed treatment significantly increased the concentration of both vaccenic acid and conjugated C18:2 in the milk fat. This has also been observed by both Jahreis *et al*. (1996) and Stanton *et al*. (1997). When the cows were turned out to grass, the concentration of these fatty acids increased significantly, regardless of the supplement fed, and to a level above that achieved by feeding cracked rapeseed as part of a TMR. An increase in the concentrations of conjugated C18:2 and vaccenic acid have also been observed by Jahreis *et al*. (1997) and Precht (1995) respectively when cows were turned out to grass. The high concentration of conjugated C18:2 in milk from cows offered pasture has been attributed to the linoleic acid content of the grass, although the proportion of linoleic acid is low compared with α-linolenic acid (Garton, 1960). Feeding diets high in α-linolenic acid increases the rumen content of vaccenic acid as a result of incomplete hydrogenation (Czerkawski, *et al*., 1975), and Grinnari and Bauman (1999) suggested that the ruminant mammary cells are able to synthesise conjugated C18:2 from vaccenic acid. Although it is possible to increase the concentration of conjugated C18:2 in the milk of cows offered a TMR by supplementing the diet with cracked rapeseed, the concentration can be exceeded still further by including fresh herbage in the diet. There is evidence in the literature that conjugated C18:2 has beneficial effects on human health, including the prevention of cancer, atherogenesis, modulation of immune function and obesity.

It has previously been noted that the feeding of high levels of rapeseed meal in early lactation has resulted in poor herd fertility, which was possibly due to excess rumen available protein (Butler, 2000; McEvoy *et al*.,1997), which was not balanced with adequate rumen fermentable energy. This was not observed in this study, as there were no significant differences between treatments in the number of days to conception, the calving index, or the number of services per conception. However, it should be noted that the number of cows per treatment was extremely small for determining differences in fertility parameters. Although the inclusion of cracked rapeseed in the diet of the cows did not have a significant effect on fertility, there was a numerical increase in the number of days to conception and calving index. This corresponded to lower blood thyroxine concentrations for the cracked rapeseed treatment. The anti-nutritive factors in rapeseed are known to interfere with thyroid function and this is reflected in reduced levels of circulating thyroxine. However hormone concentrations are always difficult to interpret. Murphy *et al*. (1995b) included 1.65 kg rapeseed in the diet of dairy cows in early lactation in a TMR and continued this level of supplementation when the cows were turned out to grass after two weeks of the study. Calving to first service and calving to conception were unaffected by treatment (80%, 94 d and 74%, 82 d respectively for the control and rapeseed). A long-term study over three lactations supplementing groups of cows with zero or two levels of rapeseed meal and seed (1.4 and 3.4 kg DM per day) showed no significant differences in fertility or thyroid function in multiparous cows. In primiparous cows at the highest level of rapeseed feeding, glucosinolates had a very mild suppressive influence on thyroid hormone release (Ahlin *et al*., 1994).

Rapeseed contains goitrogenic compounds that reduce the availability of iodine to the animal. Iodine is required for the synthesis of the thyroid hormone, thyroxine, which regulates the rate of metabolism (NRC, 1989). Among the signs of a subclinical iodine deficiency is a suppressed immune system resulting in increased incidences of foot rot and respiratory diseases (Puls, 1994). Although blood thyroxine was significantly reduced for the cracked rapeseed diet there was no significant effect on locomotion, incidence of lameness or laminitis for either of the rapeseed treatments.

The data relating to the economics of milk production indicate that the rapeseed meal and cracked rapeseed treatments were equivalent to or better than the control. However, these data are greatly influenced by the cost of the alternative feed ingredients relative to the rapeseed products and to the milk payment scheme the individual farmer is contracted to. It should also be noted that the figures are associated with a relatively small number of cows and so should be treated with caution.

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Appendix 1 Applicable results for Year two of the study

In year 2 there were 18, 18 and 14 cows for the control, rapeseed meal and cracked rapeseed treatments respectively that continued from year 1. The large spread in calving pattern both within and between the treatment groups meant that it was very difficult practically to manage the experiment. As the cows calved they were allocated to their treatment groups but for practical purposes the groups were made up to twenty cows with additional cows, these were removed as and when the treatment cows calved. The results presented within this appendix are those that can be compared with year 1 and between treatments.

The mean liveweights for the cows in each treatment at calving at the beginning of year 2 were 663, 653 and 658 kg for the control, rapeseed meal and cracked rapeseed respectively. These liveweights were 21, 44 and 28 kg heavier than the corresponding weights at calving in year 1. The increase in liveweight between years was to be expected as each group contained three primiparous cows in year one that would not yet have reached their mature liveweight. The condition scores at calving were slightly lower in year 2 compared with year 1, although the reduction in score was similar for each treatment (2.5, 2.4, 2.8 in year 1 compared with 2.3, 2.2 and 2.4 in year 2 for control, rapeseed meal and cracked rapeseed respectively).

The effect of study year and treatment on mean milk yield for the first 13 weeks of lactation is summarised in Table A1. There was a significant increase in mean weekly milk yield for the rapeseed meal treatment ($P<0.02$) for year 2 over the first 13 weeks of lactation. The precise statistical significance is difficult to obtain in year 2 because of the imbalance of the cows going onto the treatments. When year 1 data were analysed in the same way as for data for year 2, similar results (time effect - $p<0.001$; treatment effect – $p<0.007$)) were obtained.

Table A1 *The effect of study year and treatment on mean milk yield (kg/d)*

	Year of study	
Treatment	1	2
Control	36.3	37.0
Rapeseed meal	37.6	38.3
Cracked rapeseed	36.4	37.4

Milk quality was determined in year 2 in October, November and December, and these data are summarised in Table A2. There was a significant effect of treatment on the milk fat content ($P<0.05$) and the quantity of milk fat and milk protein produced, whereas there was no significant effect on milk protein content. It is difficult to interpret these data as milk quality alters with stage of lactation. The stage of lactation within a treatment group alters by month, due to cows calving and being added to the group. Each group also has a different spectrum of stage of lactation. This was always going to be a problem with the second year data.

Table A2 *Effect of treatment on milk yield and composition*

	Treatment		
	Control	Rapeseed meal	Cracked rapeseed
Milk yield (kg)	37.3	37.4	37.1
Milk fat (g/kg)	39.2	39.0	37.6
Milk protein (g/kg)	32.0	32.9	32.3

Samples of blood were taken from cows in October and analysed for urea, ammonia and thyroxine content.. The results of these analyses are summarised in Table A3. Using a one-way analysis of variance, it was observed that there was no significant effect of treatment on blood urea, ammonia or thyroxine content in years one and two with the exception of blood urea in year 2. Blood urea was significantly higher for the rapeseed meal treatment compared with the cracked rapeseed treatment. The opposite was true in year 1. In year 2 the animals went onto treatment when they calved rather than being blocked onto treatments, and there is therefore a wider spread of the treatments in terms of stage of lactation.

Table A3 *Effect of year of study and treatment on the urea, ammonia and thyroxine content of the cows' blood*

	Treatment					
Concentration of metabolite in blood	Control		Rapeseed meal		Cracked rapeseed	
	Yr. 1	Yr.2	Yr. 1	Yr.2	Yr. 1	Yr.2
Urea (mmol/l)	8.5	6.2	5.7	6.9	7.3	5.5
Ammonia (μmol/l)	96	78.6	137	65.7	135	71.5
Thyroxine (nmol/l)	51	52	58	48	49	51

Herd health

The incidences of lameness and mastitis that were observed in the different groups of cows over the two study periods are summarised in Table A5. The data for Year 2 refers to the short period (13 weeks) for which the cows were kept on the experiment, whereas the data for Year 1 refers to the whole lactation.

Table A5 *Effect of study year and treatment on herd health*

	Treatment					
	Control		Rapeseed meal		Cracked rapeseed	
	Yr. 1	Yr.2	Yr. 1	Yr.2	Yr. 1	Yr.2
Proportion of cows with cases of mastitis (single or multiple)	0.2	0.39	0.25	0.53	0.45	0.21
Incidence of lameness	0.35	0.00	0.05	0.05	0.25	0.00
Locomotion score						
Early lactation	2.11	2.11	1.9	1.59	2.00	1.69
Late lactation	2.16		1.91		1.93	

For both years 1 and 2, there was no statistically significant difference ($P>0.05$) between treatments in the incidence of mastitis between October and December inclusive (Fisher Exact test). However, the number of animals with mastitis in year 1 was significantly different from that of year 2 ($P = 0.018$), there being 5 cases and 55 non-cases for year 1 and 13 cases and 37 non-cases for year 2.

Locomotion scores appeared slightly improved in year 2 compared with year 1. Analysis of year 1 locomotion data, divided into stage of lactation, showed that there were no statistically significant differences ($P>0.05$) for early or late lactation using the Kruskal-Wallis test. No significant differences between treatments were observed in early lactation in year 2 either. When dietary treatments were ignored, there were no statistical differences (Mann-Whitney U-test, $p>0.05$) for locomotion score for early vs. late lactation in year 1, or for early lactation in year 1 vs. early lactation in year 2.

Foot lesions at 12 weeks post-calving

Foot lesion assessments were carried out 12 weeks post-calving in both years 1 and 2. The mean area scores for foot lesions for year 2 at 12 weeks post-calving are presented in Table A6. There was no observed statistical difference between scores for the three treatments ($P>0.10$) in either year.

Table A6 *The effect of study year and treatment on the lesion scores of different areas of the foot 12 weeks post calving*

	Treatment					
	Control		Rapeseed meal		Cracked rapeseed	
Lesion score	Yr. 1	Yr.2	Yr. 1	Yr.2	Yr. 1	Yr.2
White line haemorrhage						
Area 1	0.60	1.61	0.05	0.28	1.10	1.07
Area 2	1.10	1.78	0.65	0.33	0.85	1.57
Area 3	4.95	1.44	6.15	0.33	3.95	1.29
Sole haemorrhage						
Area 4	5.60	1.17	4.55	0.94	4.65	0.71
Area 5	2.45	1.0	2.35	0.72	2.25	0.43

Fertility

In year 2 there were 18 cows in the control group, 18 in the rapeseed meal group and 14 in the cracked rapeseed group. Of these, 6, 5 and 4 cows respectively were not served for various reasons in the twelve weeks of the Year 2 experiment (in both the control and the rapeseed meal groups there were two cows that were being treated for pyometrius). The fertility data that were recorded in year 2 are summarised in Table A7. It is worth noting that the recordings of milk progesterone content indicated that the cows came back into oestrus 23, 20 and 25 days post-calving for the control, rapeseed meal and cracked rapeseed treatments respectively in year 2. From these data, it would suggest that (within the limited time period for year 2) the cows were not experiencing any significant fertility problems.

Table A7 *Effect of study year and treatment on aspects of fertility*

	Treatment					
	Control		Rapeseed meal		Cracked rapeseed	
	Yr. 1	Yr.2	Yr. 1	Yr.2	Yr. 1	Yr.2
Days to 1st service	55.4	59.5(12)	58.3	59.6(12)	57.9	53.1(10)
Days to conception	77.65	47(2)	85.6	53(1)	89.06	50(5)
Calving index (d)	359.6	329(2)	367.6	335(1)	371.1	332(5)
No. in calf to 1st service	0.4	-	0.5	-	0.35	-

Numbers in parentheses denote the number of animals that the data relate to