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THE NUTRITIVE VALUE FOR LIVESTOCK OF UK OILSEED RAPE AND RAPESEED MEAL

by

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ABSTRACT

A review was made of the literature to investigate the nutritive value of rapeseed products for livestock, with particular emphasis on rapeseed grown in the UK. There were insufficient data to concentrate solely on these varieties, and further research is needed to characterise modern varieties of UK-grown oilseed rape.

Feed intake and performance of livestock fed diets containing rapeseed meal are largely determined by the glucosinolate content of the feed, and modern varieties with low concentrations of glucosinolates are more readily acceptable than the older varieties were. Low glucosinolate rapeseed meal can be used as freely as soyabean meal in the diets of adult ruminant livestock. It can be included in the diets of broilers at rates of up to 200 g/kg, and in finishing pigs at rates of 150 g/kg. However, it is excluded from the diets of most laying hens because of the sinapine present in rapeseed meal that can cause a fishy taint in the eggs of brown-feathered birds. The sinapine content of rapeseed will need to be reduced considerably before producers would be able to include rapeseed products in the diets of their laying flocks.

Full fat rapeseed needs to be finely ground if it is to be utilised efficiently by pigs and poultry. It can be fed to dairy cows as a source of energy and protein, and to alter the fatty acid composition of milk to one that may confer health benefits to people who consume it. However, it is less palatable than rapeseed meal. Among low glucosinolate varieties of rapeseed, there is relatively little difference in the chemical composition between varieties, and little evidence that yellow-coated varieties are any more digestible than brown-coated varieties. However, differences in the amino acid composition of different varieties have not been investigated. There also appears to be little effect of processing on the nutritive value of rapeseed meal, but this has not yet been investigated in the UK.

Future research on rapeseed meal should investigate the effect of UK-grown variety on the amino acid composition and digestibility by different classes of livestock. The development of varieties with low concentrations of sinapine should be pursued, together with the development of effective treatments to reduce the sinapine content of the rapeseed meal. The potential for using rapeseed meal derived from industrial rapeseed (with a high concentration of erucic acid) should be investigated. Research should also address the possible negative effect that rapeseed has on the fertility of heifers, and technology transfer might demonstrate the safe use of relatively high concentrations of rapeseed products in the diets of different classes of farmed livestock.

1. INTRODUCTION

In temperate countries such as the UK, oilseed rape is the only commercially viable crop that provides edible oil (Hill, 1991; Smithard, 1993). The rapeseed meal that is produced by the extraction of this oil is the major locally produced high-protein feed for livestock (Hill, 1991). These attributes of oilseed rape, combined with incentives from the European Union, have resulted in the crop area of oilseed rape increasing from 125 000 ha in 1981 (Smithard, 1993) to 418 000 ha in 2002 (DEFRA statistics). The use of whole oilseed rape in the diets of livestock has also increased in recent years, as the oil provides a concentrated source of energy. In addition, its fatty acid profile can result in changes to the fatty acid profile of meat, milk and eggs that may confer health benefits to the humans who consume them. However, there are some longstanding concerns about the use of rapeseed products in livestock diets. These arise from the presence of a range of anti-nutritive factors in the seed. Some of these have been largely bred out of modern genotypes of oilseed rape, while others could potentially be neutralised by processing of the seed. The purpose of this review is to examine the potential for improving the nutritive value (and increasing the inclusion rate in livestock diets) of varieties of oilseed rape grown in the UK.

2. VARIETIES OF UK OILSEED RAPE

There are currently 14 spring-sown *Brassica campestris* double low varieties on the HGCA Recommended List. The 'double low' descriptor refers to a low concentration of both erucic acid and glucosinolate, which are the two main anti-nutritive factors found in oilseed rape. Of these 14 varieties, four of these are fully recommended (cv Concept, Senator, Estrade and Sprinter). The majority of these are conventional varieties, with only Concept being a hybrid variety. Four varieties are provisionally recommended (Heros, Haydn, Mozart and Dorothy). Of these varieties, Heros and Dorothy are new to the list. The remaining varieties (Mistral, Jura, Liquido, Corsair, Liaison and Maskot) are now becoming outclassed. However, spring sown oilseed rape constitutes just 5% of the UK market, in terms of both area cultivated and production (DEFRA statistics). The winter-sown varieties of *B. napus* are therefore more important in terms of determining the contribution that rapeseed products can make to the nutrition of farmed livestock.

There are currently eight double low varieties of winter oilseed rape on the HGCA Recommended List. Of the fully recommended varieties, four are hybrids (Gemini, Cohort, Pronto and Synergy) while the others (Escort, Fortress, Madrigal and Herald) are conventional varieties. There are a further seven provisionally recommended hybrid varieties (Royal, Disco, Elan, Agenda, Spirit, Complex and Mendel), and five conventional varieties (Winner, Recital, Courage, Shannon and Canberra). The conventional variety Lipton, while still on the recommended list, is becoming outclassed.

These varieties have been evaluated in terms of their agronomic characteristics, resistance to disease, yield and quality. However, the nutritional qualities that were investigated were only their oil and glucosinolate

contents. There has been no systematic evaluation of these varieties in terms of their protein quality and content, and so it is not known whether they differ significantly from each other, or from non-UK varieties of oilseed rape in terms of their nutritive value to livestock. One characteristic that is worth noting is that spring oilseed rape (*B. campestris*) generally has a lower glucosinolate content than that of winter oilseed rape (*B. napus*, Hill, 1991). The data presented in the HGCA Recommended List suggested a mean glucosinolate content of recommended varieties of spring oilseed rape of 14.0 μmol/g DM (with a range of 12.9 to 15.8 μmol/g DM). The mean content in winter oilseed rape was 16.0 μmol/g DM (range 12.5 to 22.6 μmol/g DM; NIAB, 2002). In the virtually oil-free meal, these gluocosinolate contents would equate to a range of 21.7-26.6 μmol/g DM with spring-sown varieties and 21.0-38.0 μmol/g DM with winter-sown varieties. Since 95% of the UK rapeseed meal market consists of winter-sown oilseed rape, this means that UK-grown rapeseed meal will have relatively high concentrations of glucosinolate. In Canada and USA, the standard for glucosinolate content in dried canola meal is set at a maximum of 30 μmol/g DM (Canadian Food Inspection Agency, 1995; American Association of Feed Control Officials Inc., 1998), and since 1991 the maximum allowable concentration of glucosinolate in low-glucosinolate cultivars in the EU has been 20 μmol/g (Moss, 2002). The UK recommended varieties of oilseed rape are at the upper end of the range of double low varieties, as the range cited by OECD (2001) was 6-29 μmol/g in the oil-free meal. Assuming a moisture content of 90 g/kg, this would be equivalent to 7-32 μmol/g DM.

3. NUTRITIVE VALUE OF OILSEED RAPE AND RAPESEED MEAL TO LIVESTOCK

Full fat rapeseed (FFR) is a valuable source of energy and protein, while rapeseed meal (RSM) is a protein-rich feed. The high oil content of the whole seeds limits the amount of FFR that can be incorporated in the diets of ruminant livestock, and the utilisation of both feeds is limited by the anti-nutritive factors that are present. The values of both FFR and RSM compared with other whole oilseeds and extracted meals is also affected by the relative amino acid and fatty acid compositions, and the relative digestibility of the seeds. There are few published data comparing the nutritive value of different varieties of rapeseed, and none in which modern varieties have been compared with older, more established cultivars to determine whether plant breeding programmes have affected the nutritive value of FFR and RSM. It can therefore only be assumed that the greatest impact of plant breeding on the nutritive value of rapeseed products has been on the effects of reduced concentrations of erucic acid and glucosinolates. However, the effect of variety on the amino acid and fatty acid composition of the seed is something that should be investigated.

3.1. CHEMICAL COMPOSITION

3.1.1. Protein, oil and carbohydrate fractions

Full fat rapeseed is a yellow/black meal of average palatability (Ewing, 1997) that has become an accepted dietary ingredient in broiler feed because of its high energy content and relatively low price (Liu *et al*.,

1995). Compared with the more commonly used rapeseed meal, the oil and energy contents are higher while its protein content is lower. Compared with full fat soya, the digestibility in all species of full fat rapeseed is lower, and this is associated with a higher concentration of non-starch polysaccharides and lignin in rapeseed compared with soya (Liu *et al*., 1995). The 'double low' varieties of oilseed rape that are now fed to livestock commonly have a brown seed coat. However, yellow-coated 'triple low' varieties with a low tannin content have also been developed as an alternative (Agunbiade *et al*., 1991). In an evaluation of one such triple low variety (*B. campestris* SVO 333) by Agunbiande *et al*. (1991), it was observed that the digestible energy content in pigs of full fat rapeseed (and rapeseed meal) was improved compared with published data for high-glucosinolate varieties of oilseed rape. However, there was no such apparent advantage over more conventional double-low varieties, which raises doubts as to whether the reduction in the fibre and tannin contents of seed coats of triple low varieties confer any nutritional advantage with growing pigs (Agunbiade *et al*., 1991). Similarly, Vanhatalo *et al*. (1995) observed that differences between brown and yellow varieties of rapeseed meal were minor in terms of their effect on intestinal protein digestibility of rapeseed meal in cows. It was also noted by Liu *et al*. (1995) that the yellow-coated varieties of FFR could not necessarily be assumed to be more digestible than the traditional brown-coated varieties.

The chemical composition of full fat rapeseed from double low varieties (Ewing, 1997) and the triple low variety studied by Agunbiade *et al*. (1991) is presented in Table 3.1. As a comparison, the chemical composition of full fat soya is also presented (from data collated by MAFF, 1990). Full fat soya is a richer source of protein, but the energy content of FFR is higher because of its higher lipid content. The triple low variety of FFR had a crude fibre content similar to that of full fat soya, but its lipid and protein contents were more characteristic of FFR.

Table 3.1. *Chemical composition of full fat rapeseed and full fat soya (Agunbiade et al., 1991, Ewing, 1997)*

	Full fat rapeseed		Full fat soya
	Double low	Triple low	
Dry matter (g/kg fresh)	900	937	898
Chemical composition (g/kg DM):			
Organic matter	950	955	946
Crude protein	220	211	415
Crude fibre	72	53	48
Acid hydrolysed ether extract	460	454	229
Neutral detergent fibre	197		122
Acid detergent fibre	99		82
Starch	25		15
Sugars	48		76
Nutritive value:			
Digestible energy (pigs), MJ/kg DM	19.0	19.0	
ME[1] (ruminants), MJ/kg DM	19.1		15.5
ME[1] (poultry), MJ/kg DM	19.8		16.2

[1]ME: metabolisable energy.

There have been some suggestions that seed size can affect the chemical composition of oilseed rape, with large seeds having a higher lipid and protein content but lower fibre content than small seeds (Mińkowski, 1999). Liu *et al*. (1995) observed that there was a higher concentration of fibre constituents in small seeds (those that could pass a 1.75 mm screen), while the lipid and gross energy content was higher in large seeds. These differences were small, as were those observed by Mińkowski (1999) when comparing seeds of >2.0<2.5 mm and >1.6<2.0 mm (Table 3.2). However, the digestibility by broilers of dry matter, protein, lipid and gross energy was significantly greater in large seeds compared with small seeds, and this was attributed to the higher fibre content of the smaller seeds (Liu *et al*., 1995).

Table 3.2. *The effect of seed size on the chemical composition of whole rapeseed (Liu et al., 1995; Mińkowski, 1999)*

	Large seeds[1]	Small seeds[1]	Reference
Dry matter (g/kg fresh)	944	945	Liu *et al*. (1995
	938	942	Mińkowski (1999)
Chemical constituents (g/kg DM):			
Organic matter	937	929	Liu *et al.* (1995)
Crude protein	223	220	Liu *et al.* (1995)
	398	394	Mińkowski (1999)
Ether extract	497	487	Liu *et al.* (1995)
	488	479	Mińkowski (1999)
Crude fibre	114	122	Mińkowski (1999)

[1]Large and small seeds were >2.0 mm and <1.6 mm respectively (Mińkowski, 1999) or separated by a 1.75 mm screen (Liu *et al.*, 1995).

Compared with full fat rapeseed, rapeseed meal has a high protein content but lower energy content. The mean chemical composition of a range of samples of rapeseed meal is presented in Table 3.3. These data were produced by MAFF (1990), and so would not include more modern genotypes of rapeseed meal available in the UK. However, more recent data (Moss and Givens, 1994) showed little difference in the chemical composition of rapeseed meal, and the chemical composition of rapeseed meal fed to cows in a recently funded HGCA project (No. OS59) was also similar. Differences in the chemical composition of rapeseed meal made from different UK varieties of oilseed rape is currently being investigated in a separate LINK study funded by DEFRA, HGCA and Cargill plc.

As a comparison, the mean chemical composition of soyabean meal is also presented in Table 3.3, as this is the standard by which other oilseed meals are compared (Aherne and Kennelly, 1985). The nutritive value of rapeseed meal is inferior to soyabean meal, having a lower crude protein content (402 compared with 493 g/kg DM) and higher fibre content. The high fibre content in rapeseed meal is a consequence of the rapeseed hull, which, compared with soyabean meal, forms a relatively large proportion (16%) of the whole seed (Hill, 1991). Attempts to mechanically remove the hull have not resulted in a commercially viable product, but the difficulty in removing the seed coat does mean that the composition of rapeseed meal is

relatively uniform (Hill, 1991). This is in contrast to the situation with soyabean meal, in which the hull can be removed or added at relatively little cost (Hill, 1991). The fibre content is higher in brown-coated varieties of rapeseed meal compared with varieties with thinner, yellow coats. However, as was referred to in Section 3.1.1, it was observed by Liu *et al*. (1995) that yellow varieties of oilseed rape cannot be generally considered more digestible than the traditional brown-coated varieties. The higher fibre content of rapeseed meal compared with soyabean meal results in the digestibility of rapeseed meal by monogastric species being lower than that of soyabean meal. Diets containing canola meal were observed to be 8% less digestible than diets containing soyabean meal when fed to growing and finishing pigs (Thacker, 2001).

Table 3.3. *The chemical composition of rapeseed meal and soyabean meal (MAFF, 1990)*

Determination	Rapeseed meal				Soyabean meal (extracted)			
	Mean	Min.	Max	n[1]	Mean	Min.	Max	n[1]
Dry matter (g/kg fresh)	899	882	929	17	886	875	902	9
Chemical composition (g/kg DM):								
Crude protein	402	321	432	17	493	400	531	15
Crude fibre	111	71	141	17	70	48	91	12
AHEE[2]	54	25	83	13	27	23	32	5
NDF[3]	295	247	459	17	125	65	185	11
ADF[4]	206	169	324	17	91	39	139	11
Cellulose	141	70	229	13	45	28	67	5
Lignin	53	26	124	16	14	6	22	11
Starch	40	4	86	14	24	8	54	11
NCD[5]	766	724	789	16	904	899	910	5
IVD[6]	644	377	696	17	819	775	851	11
WSC[7]	103	90	117	7	107	82	126	6
Sugars	107	105	110	5	100	86	120	6

[1]Number of samples; [2]Acid hydrolysed ether extract; [3]Neutral detergent fibre; [4]Acid detergent fibre; [5]Neutral detergent cellulase digestibility; [6]*In vitro* digestibility; [7]Water soluble carbohydrates.

The vast majority of rapeseed oil is removed by a combination of crushing the seeds followed by extracting the remaining oil in solvent. The residue from this process is rapeseed meal. An alternative means of removing the oil omits the extraction process. A smaller proportion of the oil is removed by such an expeller process, and the residue that is left (rapeseed expeller or rapeseed cake) therefore has a higher lipid content compared with rapeseed meal. The market availability of rapeseed cake is much lower than rapeseed meal. However, the effect of expelling rather than extracting the oil may be observed by comparing the chemical compositions of rapeseed meal and rapeseed cake in Table 3.4. These data are from work reported by Kracht *et al*. (1999a,b) using German varieties of oilseed rape. In their study, they also investigated the effect of hulling the cake or meal, and these results are also presented. Although the absolute values for UK varieties of oilseed rape may be different, the relative effects of expelling, extracting and hulling will be the same. The greatest differences between rapeseed cake and rapeseed meal are in their lipid and protein contents.

Differences in the carbohydrate contents of the two feeds are relatively small, but rapeseed meal has over 20% more protein and 80% less lipid than rapeseed cake. Hulling the cake or the meal reduces the fibre content by about 40%, but the effect on the lipid, protein and sugar content is relatively small. The removal of the hull increased the digestibility of organic matter and crude protein of rapeseed cake by piglets by 15 units (Kracht *et al*., 1999a). The increase in digestibility by pigs was less marked, being approximately 10 units (Kracht *et al*., 1999a). The response to hulling rapeseed meal was smaller, being approximately 10 units for both piglets and pigs (Kracht *et al*., 1999b).

Table 3.4. *Chemical composition of intact and hulled rapeseed meal and cake (Kracht et al., 1999a,b)*

Chemical composition (g/kg DM)	Rapeseed	Rapeseed cake		Rapeseed	Rapeseed meal	
		Intact	Hulled		Intact	Hulled
Organic matter	960	932	927	961	923	918
Crude protein	181	321	363	198	396	424
Ether extract	495	120	128	495	21	21
Crude fibre	66	102	61	64	117	72
NDF[1]	157	253	151	164	286	193
ADF[2]	145	197	120	144	209	135
Lignin[3]	90	80	73	60	88	44
Sugar	52	112	135	49	105	120

[1]Neutral detergent fibre, [2]Acid detergent fibre, [3]Measured as acid detergent lignin.

3.1.2. Amino acid composition

With regard to the amino acid composition of rapeseed products, there is little difference in the amino acid contents of low and high glucosinolate rapeseed varieties, and both compare favourably with full fat soya (Aherne and Kennelly, 1985). Although soya contains more lysine than does rapeseed, the methionine plus cystine content of rapeseed is higher (Aherne and Kennelly, 1985). There is also little difference in the amino acid composition of small and large seeds, even though small seeds have a higher proportion of hull (and lower proportion of germ) than large seeds (Liu *et al*., 1995). It is not known whether there is any substantial difference in the amino acid composition of modern varieties of oilseed rape. The amino acid composition of full fat rapeseed and rapeseed meal is presented in Table 3.5 (MAFF, 1990; AmiPig, 2000). The extraction of oil does not affect the relative proportions of individual amino acids, and so although their concentration in rapeseed meal is greater than in full fat rapeseed, the amino acid profile would be unaffected. Similar analyses are presented for full fat soya and soyabean meal as a comparison. The higher protein content of full fat soya and soyabean meal compared with the rapeseed equivalents results in the concentration of amino acids being higher in the soya products compared with rapeseed.

Table 3.5. *The amino acid composition of rapeseed and soyabean products (MAFF, 1990; AmiPig, 2000).*

Amino acid	Concentration of amino acids (g/kg DM)			
	Full fat rapeseed	Full fat soya	Rapeseed meal	Soyabean meal
Alanine	9.4	16.6	16.4	22.6
Arginine	13.5	27.8	21.5	39.0
Aspartate	16.3	42.8	25.4	56.8
Cystine	5.0	5.8	2.1	6.9
Glutamate	38.0	73.9	60.9	87.9
Glycine	10.8	16.4	18.1	21.7
Histidine	6.3	12.8	11.2	15.7
Isoelucine	9.0	18.2	14.8	25.2
Leucine	14.5	29.6	25.1	40.4
Lysine	13.2	24.2	21.9	33.4
Methionine	4.8	5.5	7.2	6.9
Phenylalanine	8.9	20.4	15.4	26.9
Proline	14.2	21.5	23.4	28.4
Serine	9.4	18.6	15.7	27.0
Threonine	9.4	15.7	16.5	20.5
Tryptophan	3.1		4.7	
Tyrosine	6.5	14.7	11.6	19.1
Valine	11.4	19.5	18.7	28.8

3.1.3. Fatty acid composition

Whereas full fat rapeseed is a relatively poor source of protein compared with rapeseed meal, it is a rich source of fatty acids. It is also a rich source of both mono and polyunsaturated fatty acids, and is a particularly rich source of linolenic acid (C18:3). The concentrations of individual fatty acids in full fat rapeseed and rapeseed meal are presented in Table 3.6. Again, the corresponding values for soya products are also presented as a comparison.

Table 3.6. *The concentration (g/kg DM) of individual fatty acids in rapeseed and soyabean products (MAFF, 1990).*

Fatty acid	Full fat rapeseed	Full fat soya	Rapeseed meal	Soyabean meal
C16:0	15.3	22.6	1.8	1.6
C16:1	3.5		0.41	
C18:0	3.5	7.8	0.41	0.41
C18:1	115	47.4	13.5	2.0
C18:2	59.6	122.4	7.0	6.4
C18:3	20.4	19.7	2.4	1.2

3.2. PROTEIN QUALITY

The protein quality of a feed for pigs and poultry is a function of the digestibility of the protein fraction of the feed, and also the relative concentrations of the component amino acids of the protein. For a ruminant animal, protein quality is a function of the rumen degradability of the feed, the digestibility of the undegraded fraction, and the amino acid composition of that digestible, undegraded fraction. A high quality protein feed for a ruminant animal is one that has a high quality amino acid profile, is relatively resistant to degradation in the rumen, but is also readily digested in the small intestine.

3.2.1. Full fat rapeseed

The digestibility of full fat rapeseed crude protein was estimated in pigs by Agunbiade *et al*. (1991) using a triple low variety of rapeseed. They observed a negative linear relationship between FFR inclusion rate and digestible nitrogen content of the diet. If extrapolated to 100% inclusion rate, their data suggest that the digestibility of N in FFR is 0.855 for pigs. In broilers, a mean N digestibility of 0.687 was observed by Liu *et al*. (1995) with diets containing FFR, although this value represents the digestibility of the whole diet and not FFR alone. These workers observed that, as might be expected, the higher fibre content of small seeds resulted in a lower digestibility of protein compared with large seeds (0.679 and 0.695 for small and large seeds respectively). The difference in digestibility between small and large seeds would in fact be greater than this, because as mentioned before, these digestibilities were measured in the whole diet of which FFR constituted only 350 g/kg (Liu *et al.*, 1995). Assuming no preferential digestion and absorption of any individual amino acids, the digestibility of FFR crude protein estimated by Agunbiade *et al*. (1991) would result in digestible lysine and methionine plus cystine contents of 12.8 and 8.6 g/kg DM respectively. Corresponding values for full fat soya would be 22.3 and 10.4 g/kg DM.

For ruminant animals, FFR is a poor source of rumen undegradable protein with a concentration of just 140 g/kg DM (Mustafa *et al*., 2000). If this is fed as the sole source of protein, it is unlikely to meet the requirements of high performing animals such as high yielding dairy cows and fast growing beef and sheep (Mustafa *et al*., 2000). Any benefits in the amino acid composition of FFR are therefore likely to be lost because of the extensive degradation of FFR protein in the rumen.

3.2.2. Rapeseed meal

The ileal and faecal amino acid availability of rapeseed meal for pigs was observed to be lower than with soyabean meal (Aherne and Kennelly, 1985). The true ileal availability of essential amino acids in pigs, when comparing two double-low varieties of rapeseed meal (Regent and Candle) with soyabean meal, showed no significant difference between varieties of rapeseed, but some significant differences between rapeseed meal and soyabean meal (Table 3.7, Aherne and Kennelly, 1985). The digestibility by pigs of

amino acids in rapeseed meal is lower than in soyabean meal, and treatment of rapeseed meal to increase its digestibility would enhance its nutritive value.

Table 3.7. *The true ileal availability in pigs of essential amino acids in rapeseed meal and soyabean meal (Aherne and Kennelly, 1985)*

	Soyabean meal	Rapeseed meal variety	
		Regent	Candle
Amino acid availability (%)			
Arginine	95.0	86.8	88.5
Histidine	85.8	83.0	84.5
Isoleucine	88.5[a]	79.8[b]	79.0[b]
Leucine	88.0	83.3	82.8
Lysine	88.0[a]	78.0[b]	77.5[b]
Methionine	89.0	84.3	84.0
Phenylalanine	89.0	81.5	82.5
Threonine	81.0	73.5	71.3
Valine	78.8	70.5	69.5
Protein availability (%)	88.0[a]	78.3[b]	76.8[b]

Values with the same superscript within a row are not significantly different (P>0.05)

As with full fat rapeseed, the rumen degradability of rapeseed meal is very high. Piepenbrink and Schingoethe (1998) estimated that 60.5% of rapeseed meal protein would be degraded in the rumen, resulting in the concentration of rumen undegradable protein being just 174 g/kg DM. This was calculated assuming a rumen outflow rate of 0.07/h. At more conservative estimates of rumen outflow rate (*ca* 0.05/h), the rumen degradability of rapeseed meal will be even higher. However, these authors observed that the residue following 12 h incubation in the rumen still yielded an amino acid profile that was more similar to that of milk protein (and therefore of a higher quality for dairy cows) than that produced by blood meal, maize gluten meal or menhaden fish meal. These authors identified isoleucine as the first limiting amino acid in rapeseed meal for dairy cows.

3.3. LIPID QUALITY

The COMA report on the '*Nutritional Aspects of Cardiovascular Disease*' (Department of Health, 1994) specifically recommended a reduction in the consumption of saturated fatty acids and an increase in the consumption of unsaturated fatty acids to reduce the incidence of coronary heart disease. Moderate intakes of monounsaturated fatty acids may also help in the treatment of metabolic syndrome (Riccardi and Rivellese, 2000). Ruminant animal products have a high concentration of saturated fatty acids because of the high degree of biohydrogenation of unsaturated fatty acids in the rumen. Rapeseed oil consists primarily of oleic (51%), linoleic (25%) and linolenic (14%) acids (Khorasani *et al*., 1992). If these fatty acids could be protected from ruminal biohydrogenation and then be incorporated into ruminant meat and milk, this would

enhance the food value of ruminant animal products. One means of protecting lipids from ruminal biohydrogenation is to feed whole oilseeds. Evidence from Murphy *et al*. (1995a,b) and Mansbridge and Blake (1997) showed that when dairy cows were fed up to 4 kg/head/d of full fat rapeseed, the concentration of oleic acid in milk fat was increased by up to 30%. There was also a concomitant reduction in the concentration of medically undesirable saturated fatty acids. Increasing the concentration of oleic acid in milk fat in this way was also observed to result in an increase in the spreadability of butter (Focant *et al*., 1998). Increased spreadability of butter after refrigeration has been identified as one means of reducing the declining consumption of butter (Focant *et al*., 1998). The inclusion of full fat rapeseed in the diet of dairy cows is one means of achieving this, and is therefore a means of increasing the utilisation of oilseed rape in livestock diets.

3.4. ANTI-NUTRITIONAL FACTORS

The major anti-nutritional factors in oilseed rape are erucic acid, sequestered in the oil fraction of the seed, and the glucosinolates. The concentrations of both of these have been drastically reduced by breeding, with the term 'canola' being introduced in Canada in 1979 to describe all 'double low' cultivars. The maximum permitted concentrations of glucosinolate and erucic acid in canola are 30 μmol/g and 20 mg/g respectively. Since 1991, the maximum permitted concentration of glucosinolate in low-gucosinolate rapeseed cultivars in the EU has been 20 μmol/g. However, in addition to these anti-nutritive factors, rapeseed frequently contains tannins.

3.4.1. Glucosinolates

The glucosinolates (or thioglucosides) are themselves biologically inactive, but the hydrolysis of glucosinolates leads to the production of a number of goitrogenic and toxic compounds. The enzyme myrosinase (thioglucoside glucohydrolase EC 3.2.3.1), which hydrolyses the glucosinolates, occurs naturally in the seeds of oilseed rape but is physically separated from the glucosinolates (Smithard, 1993). Hydrolysis of the glucosinolates occurs when the seeds are crushed and when moisture is present. A measure of control of the goitrogenic activity of rapeseed meal is therefore achieved by manipulating the processing of the seed to ensure the earliest possible destruction of myrosinase. However, this approach is at best only partially successful as bacterial thiogucosidases produced in the gut will hydrolyse any residual glucosinolate in the meal (Chubb, 1982; McDonald *et al*., 1995).

The products of glucosinolate hydrolysis include isothiocyanates, thiocyanates and nitriles (Chubb, 1982). These conversions are illustrated in Figure 3.1. Isothiocyanates have a strong anti-tumourogenic effect, and help protect against cancers of the lungs and alimentary tract in humans (Johnson, 2002). However, isothiocyanates have not been detected in the milk of cows fed rapeseed meal (Hill, 1991), and so the feeding of high glucosinolate rape to cows to produce an anti-carcinogenic food for humans would not be effective. The isothiocyanates also give rise to the most actively goitrogenic compounds by being cyclized to form

oxazolidone-2-thiones (Chubb, 1982). The most goitrogenic compound is 5-vinyl-oxazolidone-2-thione, commonly known as goitrin. The glucosinolate that gives rise to goitrin is 2-hydroxy-3-butenyl glucosinolate or progoitrin (Chubb, 1982; Aherne and Kennelly, 1985). This is the predominant glucosinolate in oilseed rape, representing between 50 and 70% of the total glucosinolate concentration (Zhao *et al*., 1994). The total concentration of glucosinolates, and the relative proportions of the individual glucosinolates, is affected by the genotype of the plant and the agronomic conditions under which it is grown. Supplying large amounts of both N and S to the crop not only increases the total glucosinolate concentration, but also increases the proportion of 2-hydroxy-3-butenyl in the glucosinolate fraction (Zhao *et al*., 1994). The goitrin that is produced from the hydrolysis of progoitrin reduces the incorporation of iodine into the precursors of thyroxine, and it also interferes with the secretion of thyroxine (Chubb, 1982). The brain's hypophysis responds by increasing its secretion of thyroid-stimulating hormone (Aherne and Kennelly, 1985). The result of this is that the thyroid gland enlarges.

The thiocyanates are derived, in rapeseed meal, from the glucosinolates sinalbim and neoglucobrassin (Aherne and Kennelly, 1985). Thiocyanate inhibits the active uptake of iodine by the thyroid gland, which results in goitre. This mode of action means that the effects of thiocyanate are most noticeable in situations where iodine is limiting (Aherne and Kennelly, 1985). In addition to their action on the thyroid gland, the thiocyanates also affect the liver cells (Smithard, 1993).

The nitriles do not appear to be in themselves goitrogenic. However, the end-products of nitrile metabolism (which include thiocyanates) are goitrogenic. Nitriles have also been observed to cause death with lesions in both the liver and kidney in rats and chicks (Aherne and Kennelly, 1985), and have been suspected of being the causal agent in liver haemorrhages in poultry (Chubb, 1982).

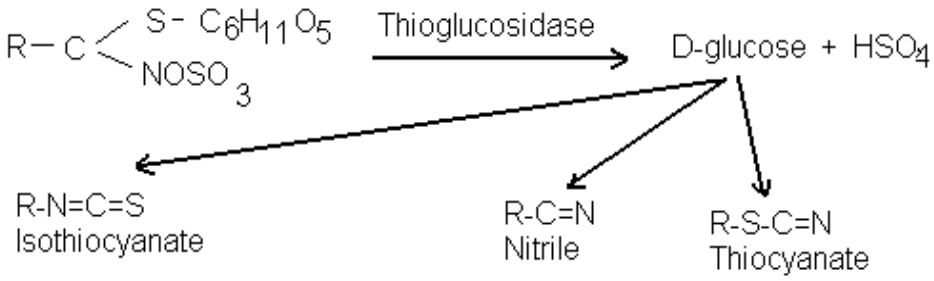

Figure 3.1. *The hydrolysis of glucosinolates to biologically active compounds (Chubb, 1982).*

3.4.2. Erucic acid

Erucic acid, a fatty acid with the configuration C22:1 n-9, has been known to cause heart lesions in experimental animals (McDonald *et al*., 1995). Feeding piglets milk replacers containing rapeseed oil high

in erucic acid led to a reduction in the number of blood platelets, and an increase in platelet size (Kramer *et al*., 1998). It also increased bleeding time in piglets compared with those that were either sow-reared, or fed milk replacers containing soyabean oil (Kramer *et al*., 1998). In general, however, the toxicity of erucic acid is not a problem when rapeseed meal is fed, as it is extracted with the oil fraction of the seed during processing. It is potentially a problem when full fat rapeseed is fed, although the quantities of erucic acid present in the double low varieties of oilseed rape are extremely small (less than 20 mg/g). Rapeseed meals with a high concentration of erucic acid could enter the animal feed market from the extraction of oilseed rape developed for industrial uses, as these do have a high concentration of erucic acid (Friedt and Luhs, 1998). Although most of the erucic acid would be extracted with the oil, some would remain in the rapeseed meal. The tolerance by livestock to such rapeseed meals may be lower than for more conventional 'double low' rapeseed meals, but no evidence could be found in the literature regarding any investigation of the use of rapeseed meal from high erucic acid varieties of oilseed rape. This is potentially a subject that would benefit from further research.

3.4.3. Sinapine and tannins

Sinapine is present in rapeseed in concentrations of between 10 and 20 g/kg fresh weight (Smithard, 1993). Sinapine produces trimethylamine when oxidised. In certain strains of hens (usually brown egg laying strains), the ability to metabolise trimethylamine is impaired because of a reduced synthesis of trimethylamine oxidase in the liver (Smithard, 1993). This causes trimethylamine to accumulate. If the ability of susceptible birds to eliminate trimethylamine is further impaired, the trimethylamine becomes incorporated in the eggs and this confers a 'fishy taint' on the eggs (Smithard, 1993). Tannins, which are polyphenolic compounds that are also present in rapeseed (Aherne and Kennelly, 1985) have been shown to inhibit trimethylamine oxidase activity *in vitro* and *in vivo* (Fenwick *et al*., 1981). This results in a further accumulation of trimethylamine in the bird and an increased concentration of trimethylamine in the egg (Smithard, 1993). Several treatments have been devised to reduce the effects of trimethylamine egg taint in rapeseed meal (Smithard, 1993).

In addition to their action on trimethylamine oxidase, tannins also form complexes with the proteins and carbohydrates in the diet to form products that are resistant to hydrolysis by digestive enzymes (McDonald *et al*., 1995). The tannins may also form a complex with the enzymes, and thereby reduce their activity. The digestibility of the protein and energy content of the diet is therefore reduced, although protein quality for ruminant animals may improve as the action of the tannins can result in a reduction in the rumen degradability of protein. Tannins may also cause damage to the intestinal mucosa and many of them interfere with iron absorption (McDonald *et al*., 1995). The condensed tannin content of rapeseed hulls is up to 60 g/kg DM, with between 70 and 96% of these tannins being insoluble (Naczk *et al*., 2000). Although the soluble tannin content varies between and within varieties, little variation was observed in the insoluble tannin content (Naczk *et al*., 2000).

4. DIETARY INCLUSION RATES

The inclusion rate of full fat rapeseed and rapeseed meal in livestock diets is limited by the effect of the anti-nutritive factors present in these feedstuffs. Generally, ruminant animals are much less susceptible to these effects and so rapeseed can be used more freely in the diets of sheep and cattle than of pigs and poultry. With the increasing reduction in the concentration of glucosinolates in oilseed rape, the inclusion rate of these feeds could be increased. However, it should be remembered that anti-nutritive factors are still present even in low-glucosinolate meals. This is of particular importance with the early-weaned pig where reduction in intake may be significant, and with breeding animals because of the possible adverse effect on the foetus (McDonald *et al*., 1995).

4.1. PIGS

Several studies have looked at the inclusion of rapeseed in various forms in pig diets. The majority of the studies have predominantly looked at the effect on reproductive performance and the thyroid with fewer looking at the effects on growth and production of meat. However most studies have used different varieties of rapeseed and different ages of pig making comparisons difficult. Lee and Hill (1983) replaced soyabean meal in the diets of pigs with rapeseed meal at an inclusion rate of 260 g/kg diet. They investigated different varieties of oilseed rape, including an unnamed British variety, and observed that the British variety resulted in the lowest voluntary intake by pigs. They also analysed the samples of rapeseed meal for glucosinolate hydrolysis products, tannins and sinapine. Lee and Hill (1983) suggested that the glucosinolates appeared to have the most marked negative effect on voluntary feed intake, as the British variety of rapeseed meal had a particularly high progoitrin content, and also the lowest voluntary intake by pigs. A further examination of their data (assuming that sinapine, glucosinolates and tannins were absent in the soyabean meal used as a control) confirms that glucosinolates had the strongest negative relationship on feed intake. When the concentrations of these anti-nutritive factors were regressed with the observed mean voluntary feed intakes of the pigs, the adjusted R^2 values were 0.975, 0.560 and 0.000 for total glucosinolates, sinapine and tannic acid equivalents respectively. The corresponding values for the standard error were 0.054, 0.224 and 0.405, and the P values were 0.072, 0.311 and 0.646.

Later work (Lee *et al.,* 1985b) compared rapeseed and soya based diets in young gilts. *B. napus* from UK and Tower from Canada were used at a 100 g/kg inclusion rate. Liveweight of the gilts fed the *B. napus* diets were lower compared with the soya and Tower diets but there were no effects on subsequent reproduction. Further work by Lee and Hill (1985a) compared the same varieties as well as Erglu (a German variety) at a 260 g/kg inclusion rate and found that the UK variety resulted in increased ovulation rates but no increase in litter size or embryo survival.

Spiegel and Blum (1993) fed growing pigs diets consisting of 150 g/kg rapeseed cake made from a single-low variety, with and without thyroxin. Pigs fed rapeseed developed goitre, although this did not affect the

concentration of serum free tri-iodothyronine. However, feed intake was severely reduced when the pigs were fed rapeseed. When intakes of rapeseed cake were similar, the growth rate of the pigs was also similar. Spiegel and Blum (1993) concluded that reduced growth rates in pigs fed rapeseed cake was a result of reduced feed intake (which was possibly a consequence of the bitter taste of glucosinolates) and that the effect of glucosinolates on thyroid metabolism was of lesser importance. Opalka *et al.* (2001) also observed that feeding gilts rapeseed meal resulted in an enlargement of the gilts' thyroid glands, but this had no effect on the performance of the gilts, or on the uterine and ovarian weights of the gilts. However, in the experiment reported by Opalka *et al*. (2001), the inclusion rate of rapeseed meal was quite low compared with that studied by Spiegel and Blum (1993). Opalka *et al*. (2001) used a double low variety of rapeseed, and the maximum inclusion rate was 120 g/kg for growing and lactating gilts and just 50 g/kg for pregnant gilts.

Schöne *et al.* (2002) observed the effects of including increasing amounts of rapeseed cake on the feed intake, growth rate and carcass quality of 60 male castrate pigs from 24 to 104 kg liveweight. A double low variety of rapeseed was used (with a glucosinolate concentration of 23.3 mmol /kg in the cake), and it was incorporated at a rate of 0, 75 or 150 g/kg diet. The high inclusion rate of rapeseed cake resulted in decreased feed intake and smaller weight gains, together with a decrease in pH and drip loss from the carcasses of some breeds. It was concluded that the intake of glucosinolate should be restricted to 2 mmol/d, which is equivalent to a maximum inclusion rate of 50 to 100 g/kg diet when the rapeseed is a double low variety. However, many more inclusion rates should be investigated before such a definitive inclusion rate could be calculated.

From these data, it is difficult to identify an ideal inclusion rate for pigs. There is little evidence that rapeseed products have a negative effect on reproduction, although the effects of high inclusion rates in pregnancy have not been investigated. The effect of the rapeseed seems to be primarily its effect on voluntary feed intake, with little evidence that any goitre that does result has any significant impact on the health or performance of the animal. However, it is not clear what the threshold of rapeseed intake is before feed intake will be adversely affected. McDonald *et al*. (1995) produced some estimates for maximum permissible inclusion rates of rapeseed meal for pigs, and these are presented in Table 4.1. These estimates are generally in accordance with the observations quoted above. However, it is likely that processing to remove the glucosinolates from the rapeseed meal would enable the inclusion rate of rapeseed meal (and full fat rapeseed) in pig diets to be increased.

Table 4.1 *Estimates of permissible maximum inclusion rates (kg/t diet) of rapeseed meal in pig diets (McDonald et al., 1995)*

	High glucosinolate rapeseed meal	Low glucosinolate rapeseed meal	
		UK	Canola
Starting pigs (7-15 kg liveweight)	40	50	80
Growing pigs (15-45 kg liveweight)	50	100	120
Finishing pigs (>45 kg liveweight)	80	150	150
Gilts	0	100	120
Sows	30	120	120

4.2. POULTRY

Rapeseed has been used in many studies with all classes of poultry. However there is no general agreement over the maximum concentration of rapeseed in poultry diets. In the case of the laying hen, some egg processors will not accept any eggs from laying birds that have been fed any rapeseed. This is due to fears of the sinapine in rapeseed meal and full fat rapeseed causing taint in the eggs. There are also limited data on the nutritive value of UK-grown rapeseed meal and full fat rapeseed, and much of the recent work on rapeseed for poultry has been done overseas especially in the Middle and Far East and also South America.

4.2.1. Broilers

Broilers are typically fed starter, grower and finisher diets with a slight increase in metabolisable energy and decrease in crude protein concentrations as the birds mature. It is well known that differences in diets and feed ingredients are more likely to have an effect in younger birds. As with the work in pigs, a range of inclusion rates and varieties of rapeseed have been used and this makes comparisons between studies difficult.

Cautious estimates of the amount of rapeseed meal that could be included in broiler diets were suggested by Szterk *et al*. (1997) and Richter *et al*. (1996a,b). Szterk *et al*. (1997) recommended maximum inclusion rates of 25, 50 and 100 g/kg diet for starter, grower and finisher broiler diets respectively. Richter *et al* (1996a) observed that broilers fed diets containing 50 g/kg rapeseed (either whole, extracted or crushed) had a reduced performance compared with birds fed a control diet containing no rapeseed. In another study, Richter *et al* (1996b) used Hybro and Ross broilers and fed them diets containing 50, 100 or 150 g/kg high glucosinolate rapeseed (16-42 mmol glucosinolate/kg) either whole or as a meal. In this study it was noted that both the whole rapeseed and the rapeseed meal resulted in a decrease in feed intake. Fasina *et al* (1997) fed broilers diets containing 0, 50, 100 or 150 g/kg rapeseed meal or full fat rapeseed. Bird weight was significantly decreased with increasing inclusion rate ($P<0.01$) and the feed to gain ratio increased ($P<0.01$). However mortality decreased with increasing rapeseed inclusion and this was more significant in the birds

fed the rapeseed meal than the whole rapeseed. However the study concluded that the level of rapeseed meal should not exceed 100 g/kg diet because of the very low feed intake in these birds.

However, Zeb *et al*. (1999) observed that broilers fed diets containing German high glucosinolate varieties of rapeseed could tolerate an inclusion rate of 150 g/kg diet, although above this rate liveweight gain and feed intake by the broilers decreased. Javed *et al.* (1999) in Pakistan also fed up to 150 g/kg rapeseed meal to Hubbard ISA broilers. The broilers were unaffected by the rapeseed and investigation into the thyroid glands also failed to reveal any effects of the rapeseed. Nascimento *et al.* (1998) fed Brazilian varieties of canola meal up to a concentration of 400 g/kg in the diet of broiler chicks. In this instance there was a decrease in feed intake and rate of liveweight gain at the higher inclusion rates of canola meal. A review by Fenwick and Curtis (1980) concluded that, if the rapeseed meal has a low glucosinolate concentration then broilers can be fed diets containing up to 200 g/kg rapeseed meal. When the concentrations of glucosinolate in the rapeseed are higher, however, lower inclusion rates must be used. The maximum inclusion rate of rapeseed meal and full fat rapeseed that can be safely fed to broilers is therefore very dependent on glucosinolate content of the rapeseed used. This will in turn depend on the variety of oilseed rape, its agronomy, and the degree and type of processing that it has undergone.

4.2.2. Laying hens

It has already been noted that there are differences between breeds of laying hens with brown egg layers being more susceptible to taint if rapeseed is fed (Richter *et al.*, 1996a; Fenwick and Curtis,1980). In white feathered birds there appears to be no problem with taint even when the diet contains up to 150 g/kg rapeseed meal (Horiguchi *et al.,* 1998).

Badshah *et al.* (2001) fed local breeds of laying hens (in Pakistan) diets containing 150, 200 and 250 g/kg rapeseed cake for 28 d. They observed no significant effect on bird health, nor any evidence of egg taint even at the high inclusion rates. The birds fed diets containing 200 g/kg rapeseed cake also produced the largest eggs. However Richter *et al.* (1996a) observed that production was affected when whole, extracted or crushed rapeseed was fed to white-feathered layers.

There are some beneficial effects of feeding rapeseed to laying birds in terms of the fatty acid composition of the eggs produced. Several studies have found that the inclusion of rapeseed in the diet of the laying hen increases the proportion of oleic, linoleic and linolenic acids and decreases the proportion of the palmitic and palmitoleic acids. Brettschneider *et al.* (1997) fed diets containing 0, 150 and 300 g/kg rapeseed to brown egg layers and observed that there was a significant increase in essential n-3 fatty acids. It has also been observed that egg yolk pigmentation can be decreased (Obadalek *et al.* 1997) even though other production factors are unaffected. However, most of the UK laying flocks consist of brown-feathered hens, and are therefore susceptible to egg taint when fed rapeseed products. It is therefore unlikely that rapeseed can be

included in diets for laying birds particularly since, as mentioned previously, the largest producer of eggs in the UK will not take eggs from flocks that have been fed any rapeseed.

4.2.3. Other poultry

In the review by Fenwick and Curtis (1980), it was concluded that broiler breeder and turkey breeder birds could be fed diets containing up to 100 g/kg rapeseed meal. For turkey poults, this inclusion rate could be increased to 200 g/kg. Layer breeder birds have a lower tolerance if glucosinolate concentrations are high and the maximum concentration they recommended was 50 g/kg (100 g/kg was considered acceptable if glucosinolate concentrations were lower.)

Growing turkeys also seem to be reasonably tolerant of rapeseed meal. A study that was reported by Vymola *et al*. (1996) fed low glucosinolate rapeseed meal to large white turkeys at inclusion rates of 0, 50, 100 and 150 g/kg. These diets supplied 0, 1.3, 2.6 and 3.9 mmol glucosinolate/kg diet respectively. The inclusion of rapeseed meal in the diet did not affect either the bodyweight of the turkeys, or their growth rate.

4.3. RUMINANT ANIMALS

As with other classes of livestock, an important factor governing the level of inclusion of rapeseed meal in the diet of ruminant animals is the protein quality. In addition, the inclusion of rapeseed meal with a high glucosinolate content, especially in the diet of rapidly growing animals and lactating cows, results in reduced feed intake and lower animal performance (Aherne and Kennelly, 1985). However, its acceptability is greatly influenced by the method of processing as well as its inclusion rate in the diet. The inclusion rate of full fat rapeseed is limited by its high lipid content as well as its relative unpalatability.

4.3.1. Calves and lambs

When high glucosinolate rapeseed meal is used in the diet of milk replacers for calves, palatability does appear to be a major problem (Aherne and Kennelly, 1985). Low-glucosinolate rapeseed meal, on the other hand, can replace up to 300 g/kg of the protein in milk replacers without depressing performance. Similarly, a review by Hill (1991) suggested that low-glucosinolate rapeseed meal could replace soyabean meal in compound concentrates given *ad libitum* as starter feeds for calves, while the use of high glucosinolate varieties of rapeseed meal generally results in reduced performance (Aherne and Kennelly, 1985). The reduced performance appears to arise from reduced voluntary intake of feeds containing high glucosinolate rapeseed meal. Thus, as with pigs, the problem appears to be one of palatability associated with the glucosinolate content of the feed. Stedman and Hill (1987) demonstrated that the voluntary intake by calves of diets containing rapeseed meal (327 g/kg diet) was affected by the total glucosinolate content of the rapeseed meal. The replacement of high glucosinolate rapeseed meal with low glucosinolate varieties, generally overcome any palatability problems experienced with calves under 100 kg (Aherne and Kennelly, 1985). It was concluded by these authors that rapeseed meal with a low concentration of glucosinolates

could be used to completely replace soyabean meal in calf starter diets. When high glucosinolate rapeseed meal is used, however, the inclusion rate of the rapeseed meal should be limited to 100-150 g/kg diet so as not to adversely affect performance. Treating the rapeseed meal to denature the glucosinolates did not prove to be effective at overcoming the low voluntary intakes observed by Stedman and Hill (1987). This would suggest that the products of non-enzymic hydrolysis of glucosinolates are at least as unpalatable as the glucosinolates themselves (Stedman and Hill, 1987; Hill, 1991). The only way to overcome this would be to extract the glucosinolates from the rapeseed in warm water (Stedman and Hill, 1987).

The voluntary intake of rapeseed meal by lambs was also related to its glucosinolate content, although the results were much less consistent (Stedman and Hill, 1987). In the absence of much data on the situation with lambs, it was concluded by Hill (1991) that low glucosinolate rapeseed meal could also be used as the sole protein supplement, although more care would be needed if high glucosinolate varieties of rapeseed were used. High glucosinolate rapeseed meals included in the concentrates fed to early weaned calves and lambs would give rise to lower rates of weight gain (Hill, 1991). These levels of performance may still be acceptable in commercial situations, however, when fast growth rates are not required (for example in the rearing of replacement heifers and ewe lambs). However, it would be preferable if a feed would permit a wide range of performance, including the maximum. Low glucosinolate rapeseed meal appears to achieve this, at least when it is incorporated in a concentrate (Hill, 1991). There is no evidence to suggest that the incorporation of rapeseed meal in the diets of calves and lambs results in any adverse effects on the carcass flavour in either cattle or sheep (Hill, 1991).

4.3.2. Adult ruminant animals

Low-glucosinolate rapeseed meal can be used as freely as soyabean meal in the diets of dairy cows (Hill, 1991; Aherne and Kennelly, 1985). The risk of encountering palatability problems when feeding low-glusocinolate rapeseed meal to adult dairy cows is minimal (Emanuelson, 1994) and both the yield and quality of milk is as satisfactory as from diets based on soyabean meal (Hill, 1991). Milk composition from cows fed low-glucosinolate rapeseed meal appears to be unaffected (Aherne and Kennelly, 1985). The published data on rapeseed products in relation to health and fertility are limited, and this is a reflection of the small number of long-term studies that have been undertaken, with sufficient number of animals to produce statistically significant results. There is some indication that the feeding of high glucosinolate rapeseed meal to heifers can reduce reproductive efficiency (Ahlin *et al*., 1994; Ahlström, 1978; Amanuelson, 1987; Lindell, 1976; Lindell and Knutson, 1976). Emanuelson *et al*. (1993) also observed that when large amounts of rapeseed meal from double low cultivars were fed to heifers, there was some indication that fertility was slightly affected. However, it was noted by Emaunuelson (1994) that as the glucosinolate content of oilseed rape continues to decline it should become increasingly safe to feed low glucosinolate rapeseed meal to adult dairy cows, even as the sole protein source.

In summary, if high glucosinolate rapeseed meal is fed, then intake should be limited to 100 g/kg of the concentrate mixture, or 50 g/kg of the total diet (Aherne and Kennelly, 1985). However, much more rapeseed meal can be fed if low-glucosinolate varieties are used. Hill (1991) concluded that rapeseed meal could be included in compound feeds at rates as high as 600 g/kg, whereas Emanuelson (1994) suggested that grain/concentrate mixes could consist of 200-300 g/kg low-glucosinolate rapeseed meal without any adverse effects. Moss (2002) observed no problems when UK-produced rapeseed meal was included in the concentrate fraction of dairy cows' diets at a rate of 360 g/kg, which constituted 190 g/kg dry matter of the whole diet. Despite these positive observations, however, dairy compound feeds in the UK still contain on average only 150 g/kg rapeseed meal, and this is partly because of continued concerns about the glucosinolate contents of rapeseed meal (Moss, 2002). With regard to sheep, Mandiki *et al*. (2002) observed no adverse effects on ewe or lamb performance when pregnant and lactating ewes were fed concentrates containing 400 g/kg low glucosinolate rapeseed meal.

Feeding large amounts of full fat rapeseed to dairy cows does reduce intake and this can adversely affect performance. However, Emanuelson *et al.* (1991) observed that 1.5 kg DM full fat rapeseeed could be included in dairy cow diets with no deleterious effects on rumen metabolism and total digestibility. Cows fed concentrates consisting of 63 and 126 g/kg full fat rapeseed also showed no significant difference in feed intake, milk yield or milk composition compared with cows fed a concentrate based on soyabean meal (Aherne and Kennelly, 1985). However, it should be noted that in the experiment referred to by these authors milk fat content was exceptionally low (19.1-23.9 g/kg milk) and this might reflect an inability to adapt (and recover from) the high fat content of diets containing full fat rapeseed (Aherne and Kennelly, 1985). Full fat rapeseed has been included in the diet of dairy cows at a rate of 147 g/kg concentrate dry matter (Moss, 2002). Milk yield and cow liveweight and condition were not affected but dry matter intake was reduced by over 1.5 kg/d. However, there were beneficial effects (in terms of human health) on the fatty acid composition of the milk produced. It would therefore seem likely that full fat rapeseed can be included in the diets of dairy cows at rates of up to 120 g/kg concentrate without encountering any problems, although the effect of full fat rapeseed on the cows' fertility may need to be confirmed (Moss, 2002).

5. STRATEGIES TO INCREASE THE INCLUSION RATE OF RAPESEED PRODUCTS IN LIVESTOCK DIETS

The value of rapeseed products as livestock feeds would be enhanced if the inclusion rates of rapeseed products in livestock diets could be increased. To achieve this, the concentrations of anti-nutritive factors need to be reduced and digestibility needs to be increased. For ruminant animals, the nutritive value of rapeseed meal and full fat rapeseed might be further increased if its protein degradability in the rumen could be reduced. Such improvements could be brought about either by reducing the concentrations of

anti-nutritive factors in the seed, or by applying cost-effective treatments to the seed to reduce the activity of the toxins that are present. This section considers the relative efficacy of these different approaches.

5.1. SEED CHARACTERISTICS

Selecting double low varieties of oilseed rape with reduced concentrations of both erucic acid and glucosinolates has obviously improved the nutritive value of rapeseed products for livestock. In addition, reducing the inputs of S and N to the crop will further reduce the total glucosinolate concentration of the seed, and the proportion of progoitrin in the glucosinolates (Zhao *et al*., 1994). For laying hens, the selection of cultivars with a low concentration of sinapine will also increase the potential inclusion rate of rapeseed products in the diet.

In addition to differences in the glucosinolate content of different cultivars, there are also differences in other chemical components of the seed. This can affect the relative nutritive values of different varieties. An illustration of this was given by Bell *et al.* (1998) who fed *B. napus* canola and *B. rapa* canola meals to pigs at inclusion rates of 150 and 300 g/kg diet. The digestible energy content of *B. napus* was 1.1 MJ/kg lower than that of *B. rapa*, and both species were less digestible than soyabean meal for both crude protein and energy. There have been other studies that have compared the nutritive value or chemical composition of different varieties of oilseed rape. However, these studies have not been integrated, and there is insufficient data to make recommendations on varieties of oilseed rape grown in the UK which give rise to rapeseed products of superior nutritive value for different classes of livestock.

It has already been mentioned that indicative seed characteristics affecting nutritive value that have been considered include seed colour and seed size. A higher apparent metabolisable energy content in broilers with yellow *B. napus* was observed compared with brown *B. napus* (Slominski, 1997). However, Agunbiade *et al*. (1991) and Liu *et al*. (1995) observed little difference in the digestibility by pigs and broilers respectively of brown compared with yellow full fat rapeseed. Vanhatalo *et al*. (1995) also observed no significant differences in protein degradability in the rumen, or apparent protein digestibility in the intestine, between brown and yellow varieties of rapeseed meal. It seems reasonable to suppose that there is as much variation within cultivars of the same seed colour as there is between brown and yellow varieties of oilseed rape. Large seeds have a higher protein and lipid contents, and a concomitantly lower fibre content, compared with small seeds (Minkówski, 1979; Liu *et al*., 1995). The nutrient digestibility by broilers of large seeds is also greater compared with small seeds (Liu *et al*., 1995). It is possible, given a large enough price differential between large and small seeds, that batches of rapeseed could be screened to separate large from small seeds. However, the difference in digestibility, while significant, is so small (about 2.5%) that it is unlikely to result in the procedure being economically viable.

5.2. PROCESSING TECHNIQUES

A potentially important source of variation, apart from differences between varieties, is the processing technique that is used in the production of rapeseed oil (and rapeseed meal or cake). Differences in the temperatures and moisture contents encountered during processing may have profound effects on the glucosinolate contents of the final products. For ruminant animals, differences in processing techniques could also affect both the extent to which the protein is degraded in the rumen and the degree to which it is digested postruminally. In a comparison of rapeseed meal taken from five different extraction plants in Canada, Kendall *et al*. (1991) observed that processing technique had little effect on the postruminal digestibility of rapeseed meal. Variation in the postruminal provision of nutrients was affected more by differences in the extent of rumen degradation than by differences in the postruminal digestibility of nutrients (Kendall *et al*., 1991). These observations suggest that alterations to the processing technique, or subsequent treatment of the rapeseed meal, may increase the protein quality of rapeseed meal by decreasing its rumen degradability without adversely affecting its postruminal digestibility. However, differences between processing plants on the effective degradability of rapeseed meal protein in the rumen were small. Indeed, at rumen outflow rates typical of dairy cows in the UK, there were no significant differences between processing plants on the effective degradability of protein in the rumen. It is not known what effect different processors might have on the nutritive value of rapeseed meal produced in the UK. However, a research programme currently underway (HGCA Project No. 2449) is considering this point.

The greatest difference in nutritive value of rapeseed products comes from the processing of rapeseed for the production of rapeseed cake rather than rapeseed meal. Rapeseed cake has a higher lipid and therefore energy content than rapeseed meal. The glucosinolate content of rapeseed cake is also lower than rapeseed meal. The concentration of glucosinolates was 28% greater in rapeseed cake compared with whole rapeseed in an experiment reported by Schöne *et al*. (1996), but this was still only 18.5 mmol/kg DM compared with the standard for canola meal of <30 mmol/kg DM (Hill, 1991).

5.3. TREATMENT OF RAPESEED PRODUCTS

Another means of increasing the nutritive value (and potentially also the inclusion rate) of rapeseed products in livestock diets is by the treatment of the whole seed, or its products after processing. Altering the processing technique in the manufacture of rapeseed cake or meal may also affect the possible inclusion rates of the rapeseed products.

5.3.1. Treatment of full fat rapeseed for pig and poultry diets

Heat treating the rapeseed to inactivate the myrosinase is an established practice by crushers to minimise the sulphur content of the oil (Smithard, 1993). The sulphur poisons the catalysts that are used in the hydrogenation of the oil for margarine manufacture, and it may also lead to undesirable smells when the oil

is used for cooking. Extrusion of full fat rapeseed increased lipid and protein digestibility by pigs, and this improved animal performance by increasing daily liveweight gain and feed conversion efficiency (Smithard, 1993). However, full fat rapeseed also requires some physical disruption, such as grinding or milling, to increase the availability of the rapeseed oil to the animal if the benefits of the feed are to be fully realised (Smithard, 1993). Castaing *et al.* (1998) investigated the effects of feeding pigs with full fat rapeseed that had been either unground, coarsely ground or finely ground. Unground seed had a digestibility coefficient of between just 0.10 and 0.20. This increased to 0.80 when the seed was coarsely ground, and digestibility was improved still further by finely grinding the rapeseed. However, the feed conversion efficiency and daily liveweight gain of the pigs was poor compared with conventional diets containing no full fat rapeseed. Clearly heat treatment as well as grinding is required when full fat rapeseed is fed to pigs.

Smithard (1993) referred to unpublished results that suggested that if full fat rapeseed was extruded and ground, it could be included in broiler diets at a rate of 400 g/kg. At this inclusion rate, liveweight gain, feed conversion efficiency and pancreas weight was similar to that observed with a conventional diet. However, if the full fat rapeseed was not heat-treated, bird performance was significantly reduced at this high inclusion rate (Smithard, 1993). The review by Smithard (1993) concluded that full fat rapeseed could be used in the diets of growing pigs and broilers provided it is both heat-treated (using a method such as extrusion) and milled. However, Dänicke *et al.* (1998) observed little additional benefit in heat treating ground, full fat rapeseed that was fed to either broilers or laying hens. Heat treatments that were investigated included 'hydro thermal', jet-sploding and micronising at temperatures of between 98 and 125^{0}C. Their work clearly demonstrated, however, the importance of physical comminution of the full fat rapeseed, especially if it was being fed to broilers. The nitrogen-corrected apparent metabolisable energy (AME_N) content was almost doubled (from 12.4 to 22.0 MJ/kg DM) when finely milled full fat rapeseed was fed to broilers instead of the whole seed. The difference in AME_N content for laying hens was less marked (increasing from 18.3 to 23.0 MJ/kg DM), but was still significant. The results reported by Dänicke *et al*. (1998) indicate that full fat rapeseed in the diets of broilers and laying hens needs to be ground to an average particle size of $\leq$ 0.56 mm, but that further heat treatment will have little effect.

5.3.2. Treatment of full fat rapeseed for ruminant diets

Full fat rapeseed has a high lipid content, which may adversely affect rumen metabolism, particularly with regard to fibre digestion. However, it is generally recognised that feeding oils in the form of unextracted whole seeds does not have such a detrimental influence compared with including free oils in the diet (Palmquist, 1983). As was described in Section 3.3, one potential means of increasing rapeseed utilisation in livestock diets is to use it to manipulate the fatty acid composition of animal products to confer human nutritional health benefits on these products. When feeding to ruminant livestock, the unsaturated fatty acids in full fat rapeseed need to be protected from ruminal biohydrogenation to bring about these beneficial changes to the composition of ruminant meat and milk fat. Feeding whole oilseeds do confer a degree of

protection to the fatty acids, but further treatment of full fat rapeseed may enhance this protection from ruminal biohydrogenation still further. Full fat rapeseed is also a rich source of protein, and so protecting the full fat rapeseed from degradation by rumen microorganisms may also decrease the rumen degradability of protein and thereby enhance the protein quality of this feed to ruminant animals.

Pallister and Smithard (1987), Emanuelson *et al*. (1991), Ferlay *et al*. (1992) and Khorasani *et al*. (1992) have investigated the use of heat treatment to enhance the nutritive value of full fat rapeseed. Emanuelson *et al*. (1991) investigated heat and steam- treated full fat rapeseed, and compared this with crushed rapeseed in the diets of dairy cows. The heat treatment was successful at reducing the degree of biohydrogenation of unsaturated fatty acids, although it did also slightly reduce the overall digestibility of these fatty acids suggesting overprotection of the lipid (Emanuelson *et al*., 1991). However, the reduced biohydrogenation of long chain unsaturated fatty acids did not result in an increased concentration of these fatty acids in the milk, perhaps because the overprotection had reduced their availability to the cow. Although the heat and steam treatment reduced the extent of ruminal biohydrogenation of fatty acids, it did not reduce the ruminal degradability of protein. If anything, the heat treatment increased protein degradability. It has been observed that the fat globules in rapeseed treated with heat and steam aggregate into large conglomerates (Emanuelson *et al*., 1991) and this was the explanation given by these authors as to why heat-treating full fat rapeseed resulted in an increased rumen degradability of protein. Ferlay *et al*. (1992) also observed little effect of extrusion on protein degradability, and they suggested that this could be because the high lipid content of full fat rapeseeds meant that physical disruption of the cells during extrusion was reduced. Pallister and Smithard (1987) did observe reduced rumen degradability of protein with extruded rapeseeds, as did Khorasani *et al*. (1992) with jet-sploding. However, Pallister and Smithard (1987) achieved overprotection of the protein so that overall digestibility of protein was decreased by heat treatment. Extruding the full fat rapeseed did result in reduced biohydrogenation of C18:1 fatty acid (Pallister and Smithard, 1987), and in contrast to Emanuelson *et al*. (1991), this also resulted in an increased absorption of C18:1 from the small intestine. However, Khorasani *et al*. (1992) observed that jet-sploding the rapeseed still resulted in organic matter degradation in the rumen being reduced, which would suggest that protection of the rapeseed oil from rumen microorganisms was not complete. These studies show that subjecting full fat rapeseed to some form of heat treatment to protect the lipid and protein fractions from ruminal degradation yields far from predictable results. More work needs to be done to optimise these treatments before the commercial value of full fat rapeseed for ruminant livestock can be reliably increased.

If the full fat rapeseed is being fed to ruminant livestock because of its oil content, then an alternative to feeding full fat rapeseeed is to feed rapeseed oil on its own. As has been said before, however, the oil in this form is much more susceptible to biohydrogenation, and is more likely to disturb the rumen fermentation. Tesfa (1992) observed that feeding 0.5 kg rapeseed oil to Friesian bulls (550 kg liveweight) significantly reduced the activities of the fibrolytic enzymes carboxymethyl cellulase and xylanase. This could have been

a result of the significant decrease in the size of the protozoal population that also occurred, as rumen protozoa are an important contributor to fibre digestion in the rumen (Tesfa, 1992). However, Pallister and Smithard (1987), when feeding an equivalent amount of rapeseed oil to mature wethers, observed no adverse effect on rumen metabolism or dietary fibre digestibility. However, the efficiency of rumen microbial protein synthesis appeared to be decreased.

To maintain efficient microbial protein synthesis, and enhance the supply of unsaturated fatty acids to the ruminant animal, some protection of free rapeseed oil may be beneficial. One such approach that has been investigated is the treatment of rapeseed oil with another compound to form an inert material. Reacting rapeseed oil with ethanolamine, for example, was observed to reduce the extent of ruminal biohydrogenation of rapeseed oil (Loor *et al*., 2002). However, this treatment did not increase the concentration of oleic acid in the milk to any greater extent than was achieved by feeding the untreated rapeseed oil (Loor *et al*., 2002).

When lipids such as rapeseed oil are fed to increase the proportion of unsaturated fatty acids in animal products, one problem that may arise is that these unsaturated fatty acids are more prone to oxidation and the production of 'off' flavours than are their saturated counterparts. One means of counteracting this susceptibility to oxidation is to increase the intake of antioxidants by the animal. Focant *et al*. (1998) observed that a high level of supplementation of vitamin E (9616 international units/d) by cows improved the resistance of milk fat to oxidation.

If the use of full fat rapeseed or rapeseed oil in ruminant diets is to be increased, more research needs to be done to develop effective means of protecting the lipid (and protein) from rumen degradation. This will also help to maintain a stable and healthy rumen fermentation in the face of the challenge from rapeseed oil. The development of an appropriate means of protecting full fat rapeseed from rumen degradation must also ensure that the increased rumen protection is not at the expense of reduced digestibility of the product in the hind gut.

5.3.3. Treatment of rapeseed meal for pigs and poultry

The objective of treating rapeseed meal for pigs and poultry is to increase its digestibility, and denature anti-nutritive factors such as the glucosinolates. A reduction in the sinapine content of the meal may also be required when rapeseed meal is to be fed to laying hens. Heating the rapeseed meal will denature the glucosinolates, but this non-enzymic hydrolysis of glucosinolates may result in products that cause as many problems as the glucosinolates themselves. The heat treatment of rapeseed may also decrease the digestibility of its protein fraction. Unless it is extremely severe (when reduced digestibility of the protein and other nutrients is then almost certain) heat treatment alone may also be unable to denature all of the anti-nutritive factors present. For example, Khattak *et al.* (2001) autoclaved rapeseed cake and included this in the diets of brown laying hens at different rates up to 250 g/kg diet. Although the inclusion of rapeseed

cake in the diet did not affect production or bird health, it was observed that the concentration of protein in the egg white decreased and there was evidence of egg taint with increased inclusion rate of rapeseed cake. It was concluded from these results that autoclaving was not sufficient to detoxify the rapeseed cake for poultry. The hydrothermal treatment of rapeseed meal did result in a decrease of sinapine content from 6152 to 50 mg/kg and of glucosinolate content from 13.8 to 1.4 mmol/kg (Jeroch *et al*., 1999). Egg production and feed conversion efficiency was still reduced when large quantities of treated rapeseeed meal were included in the diet (300 g/kg), but treatment did enable more rapeseed to be added. With untreated rapeseed, the threshold inclusion rate for affecting bird productivity was 225 g/kg. Hydrothermally treating the rapeseed meal markedly decreased the concentration of trimethylamine in the eggs and it also reduced, although did not eliminate, the liveweight loss that was observed in birds at the highest inclusion rates of rapeseed meal.

Heat treating a mixture of rapeseed meal and beans was also successful in an experiment reported by Mutalab and Smithard (1994). These authors fed broilers a rapeseed/bean mix included in a control diet at rates of 200 and 400 kg/t. Heating the rapeseed/bean mixture reduced the concentration of goitrin in the blood and jejunal contents of the birds, and also increased the digestibility of the diets. It was observed that, when birds were fed the untreated mixture, the feed conversion efficiency and rate of liveweight gain decreased as the inclusion rate of the mixture in the diet increased. However, the broilers that were fed the treated rapeseed/bean mix showed an increased liveweight gain and feed conversion efficiency with increased intake of the rapeseed/bean mix.

Work reported by Schöne *et al*. (1996) demonstrated that soaking rapeseed cake in water (11 kg water/kg rapeseed cake) and then drying the cake at 60^0C reduced the glucosinolate content of rapeseed cake from 18.5 to 0.3 mmol/kg DM. Unlike other non-enzymic treatments of glucosinolates, this treatment also resulted in the concentration of glucosinolate degradation products being undetectable. Treating rapeseed cake in this way resulted in a significant reduction in the enlargement of the pigs' thyroid and liver that was observed when rapeseed cake was included in the diet. However, there was no significant difference in the performance of pigs fed treated or untreated rapeseed cake.

An alternative approach to the use of heat was investigated by Yuqin *et al.* (2001). These workers incubated the rapeseed meal with a mixture of microorganisms to remove the anti-nutritive factors. Rapeseed meal treated in this way resulted in an increase in the liveweight of birds fed diets containing this meal at inclusion rates up to 150 g/kg diet compared with similar diets containing untreated rapeseed meal. However, decreases in liveweight were observed when the inclusion rate was increased above 150 g/kg diet, even when the rapeseed meal had been treated.

The heat treatment of rapeseed meal, or extraction of glucosinolates in water followed by evaporation, are two means by which the nutritive value of rapeseed meal may be increased for pigs and poultry. However,

anti-nutritive factors still remain in the meal, and so limits must still be set on the inclusion rate of rapeseed meal in the diets of these animals. Treatment of rapeseed meal does, however, provide the opportunity for the inclusion rates of rapeseed meal to be increased. The viability of these approaches depends on the relative prices of rapeseed meal compared with the costs of treatment.

5.3.4. Treatment of rapeseed meal for ruminants

It has been noted that, certainly for adult ruminant animals, rapeseed meal can be used as freely as soyabean meal. However, concerns remain about the effect of rapeseed meal on feed intake and there may be some benefits arising from the treatment of rapeseed meal to reduce its protein degradability in the rumen. If the nutritive value of rapeseed meal was enhanced in this way, it may encourage more producers to include rapeseed meal (or larger proportions of rapeseed meal) in the diets of their livestock.

5.3.4.1 Treatment of rapeseed meal to increase intake.

Stedman and Hill (1987) investigated the acceptability of rapeseed meal by lambs and calves, and observed that as with pigs (Lee *et al*., 1984) there was strong evidence for an inverse relationship between glucosinolate content and voluntary intake in a limited time. A range of treatments to reduce the glucosinolate content of rapeseed meal were used, and the effect that such treatment had on the voluntary intake by calves of diets containing large proportions (327 g/kg concentrate) of rapeseed meal was investigated. The treatments were based on heat (both dry and moist) and alkali, with temperatures ranging from 90 to 121^{0}C. The alkalis used were ammonia, calcium hydroxide or a combination of the two. These treatments were very effective at reducing the concentrations of glucosinolates and sinapine in the meal. However, the effect on voluntary feed intake was not as dramatic. Treatment with ammonia had no effect on intake, and while the other treatments did result in significant increases in voluntary intake, these increases were often small. This led Stedman and Hill (1987) to conclude that the use of heat and alakali to hydrolyse glucosinolates results in the production of compounds which appear to be at least as unpalatable as the glucosinolates themselves. They further suggested that probably the only satisfactory method of treating rapeseed meal to increase voluntary intake would be to extract the glucosinolates in warm water. However, it should be noted that in this early work with British varieties of rapeseed meal, the glucosinolate content (139 mmol/kg) was much higher than would be observed in current double low varieties of UK grown oilseed rape. The voluntary intake of canola meal was much greater, and approached that of soyabean meal (Stedman and Hill, 1987). It is also true that the test applied by Stedman and Hill (1987) was particularly sensitive, as it measured the intake in a 30 or 60 min period. Over longer periods of time (such as would normally be encountered in most feeding situations), the differences between varieties of rapeseed meal, and between rapeseed meal and soyabean meal, were much less obvious. The review by Hill (1991) noted that in studies where measurements of voluntary intake were obtained from situations of continuous feeding over many weeks, there was little if any difference in the voluntary intake of rapeseed meal compared with

soyabean meal. Treatment of rapeseed meal with a low glucosinolate content to increase voluntary intake by ruminant animals, if required at all, would only be necessary in situations where exposure to the feed was limited (eg. parlour feeding of dairy cows).

5.3.4.2 Treatment of rapeseed meal to reduce rumen degradability of protein.

The treatment of proteins to reduce their degradability in the rumen has been studied for many years using a number of different protein concentrates. Typical treatments include physical treatments such as heat or chemical treatments that are designed either to coat the protein with a compound that is resistant to rumen degradation, or react with the protein to form complexes that are insoluble in the rumen environment (Mustafa *et al*., 2000). It is important in the application of any such treatment that the protection from rumen degradation is not so complete as to render the protein indigestible throughout the rest of the digestive tract. It is also important that the treated feed is adequately characterised, as improvements in the supply of digestible undegraded protein do not necessarily translate into improvements in animal performance (Vanhatalo *et al*., 1995).

The use of heat to reduce the rumen degradability of dietary protein is an established practice. Heat can be applied either in the presence or absence of water, or in the process of jet-sploding which is a rapid steam treatment under high pressure. A review by Mustafa *et al*. (2000) of a number of papers concluded that dry heat treatment up to a temperature of 125^0C would result in a reduction in the rumen degradability of protein without adversely affecting protein digestion in the small intestine. Heat treating rapeseed meal to 140^0C, on the other hand, reduced intestinal digestibility of protein by 15% (Pieszka and Brzóska, 2000). It has also been demonstrated that temperature is more important than the duration of heating in protecting the rapeseed meal protein from ruminal degradation (Mir *et al*., 1984). Heating canola cake or canola meal at 125^0C for 20 min resulted in a reduction of rumen protein degradability of 33% for canola cake and 56% for canola meal (Jones, 1993, cited by Mustafa *et al*., 2000). However, when these treated rapeseed products were included in the diets of cows (110 g/kg diet), there was an increase in the yield of milk and milk protein in heifers but not in cows (Jones, 1993, cited by Mustafa *et al*., 2000). The benefits of dry heat treating rapeseed meal in terms of improved animal performance are therefore not proven. There may also be other consequences of heat-treating rapeseed meal and other protein concentrates. Park *et al*. (2000) measured the flow of phytate to the duodenum in sheep fed rapeseed meal that was either untreated or dry roasted at 133 or 143^0C. The proportion of dietary phosphorus that entered the duodenum in the form of phytate was 0.22, 0.37 and 0.55 respectively. Phytate forms an insoluble complex with phosphorus that is indigestible in the mammalian gut. In ruminant animals the phytate is usually degraded in the rumen, so that the animal is then able to absorb the phosphorus. The results of this experiment suggest that the heat treatment of rapeseed meal rendered the phytate present in the meal undegradable in the rumen. This in turn is likely to reduce the availability of phosphorus to the animal. As phosphorus intake by farm animals is reduced amidst concerns

for the environment, this effect of heat treating protein concentrates could have serious consequences with regard to the phosphorus nutrition of these animals (Park *et al*., 2000).

Heating rapeseed meal in the presence of moisture (autoclaving) is another means of reducing protein degradability. Moist heat treatment reduced the rumen degradability of protein by 17% without affecting the digestibility in the small intestine (Vanhatalo *et al*., 1995). Autoclaving at a temperature of 127^0C with steam at a pressure of 117 kPa will decrease degradability and increase the supply of digestible dietary amino acids to the small intestine if treatment is not extended beyond 45 min (Mustafa *et al*., 2000). However, these authors could find no published evidence as to whether these improvements brought about any practical benefits in terms of improved animal performance. Protein degradability is also reduced if the feed is micronised (Mustafa *et al*., 2000). However, micronisation can reduce digestibility in the whole tract when whole seeds are fed (Wang *et al*., 1999), but this was not observed when micronised, ground canola seed was fed. This suggests that the utilisation of amino acids from micronised canola seed is largely influenced by the method of processing (Mustafa *et al*., 2000).

Aufrère *et al.* (1998) investigated a range of treatments involving different temperatures for pre-heating and solvent extraction as well as different rates of steam injection. The mildest treatment, which did not heat the rapeseed meal above 60^0C, resulted in a rumen protein degradability of 0.826. This compared with the most extreme treatment that involved heating the rapeseed meal to 130^0C, extracting in solvent at 120^0C and then injecting with steam at 80 kg/h. Under this regime, the protein degradability in the rumen was reduced to 0.422. It was suggested that the digestibility of true protein in the small intestine was not affected, and if this was the case then this extreme treatment may result in an improved supply of protein to the small intestine. Even compared with the 'commercial' treatment, (which had an effective degradability 0.693), the reduction in degradability was 39%. However, whether this results in improved animal performance has not been confirmed. Feeding cows untreated concentrates containing rapeseed meal, or the same concentrate that had been expanded (heat treated) resulted in no significant differences in milk yield and composition, liveweight or liveweight change (Tesfa *et al*., 1995). This was despite the rumen degradability of protein in the concentrate being reduced from 0.764 to 0.724.

Pieszka and Brzóska (2000) investigated coating rapeseed meal with an undegradable compound to protect the protein from rumen degradation. In their experiment they used the calcium salts of fatty acids from a friable fodder fat. The proportion of calcium fatty acid salts added to rapeseed meal ranged from 0 to 300 g/kg rapeseed meal and resulted in protein degradability decreasing from 0.657 to 0.368. Intestinal digestibility was not affected, but the dilution of the rapeseed meal with such large amounts of fatty acid resulted in the supply of digestible undegraded protein only increasing from 134 to 143 g/kg diet. It is unlikely that this increase would result in any significant improvement in animal performance.

Chemical treatments that are designed to form insoluble complexes with the protein include treatment with formaldehyde, but this can result in dramatic reductions in intestinal protein digestibility (Mustafa *et al*., 2000; Pieszka and Brzóska, 2000). In the review by Mustafa *et al*. (2000), reports of feeding dairy cows formaldehyde-treated rapeseed meal had not resulted in any significant improvement in intake, milk yield or milk composition. Treating the rapeseed meal with alkali, acid, alkaline hydrogen peroxide or heating it with lignosulphonate had also shown reductions in protein degradability, but no effect on milk yield or milk composition in dairy cows (Mustafa *et al*., 2000).

Heat treatments appear to be more effective than chemical treatments at protecting rapeseed meal protein from rumen degradation. Chemical treatments also seem more prone to reducing the digestibility of the protein in the small intestine (Mustafa *et al*., 2000). Most of the studies reviewed by Mustafa *et al*. (2000) that investigated the use of treated rapeseed meal did not demonstrate any improvement in animal performance. The diet and feeding situation need to be carefully characterised to ensure that a reduction in protein degradability may be of some benefit, since it is often a supply of energy that is limiting in ruminant diets (Tesfa *et al.* 1995). Rather than investigating novel treatments for rapeseed products for ruminant animals, it may be more beneficial to identify the situations in which rapeseed products could have a key role in supplying limiting nutrients.

5.4. FEEDING STRATEGIES

Another means by which the inclusion rate of rapeseed products might be increased in livestock diets is by the manipulation of the diet or the feeding management system to overcome some of the constraints presented by the feeding of rapeseed products. The former could be achieved by the use of particular enzymes or supplements to increase the availability of nutrients in the rapeseed products. The latter might be addressed by altering the way in which concentrate feed is offered to particular classes of livestock, such as dairy cows.

5.4.1. Enzymes

Phytates in rapeseed products will chelate with minerals (particularly phosphorus) rendering these nutrients unavailable to pigs and poultry. They can also reduce the availability of protein. Work with pig and poultry diets has demonstrated that nutrient availability in diets containing rapeseed can be increased by the addition of phytases. In diets based on barley and rapeseed meal that were fed to pigs, 47% of the phytate was hydrolysed when exogenous phytases were added to the diet (Skoglund *et al.*, 1998). Krasucki *et al.* (2000) fed pigs diets that consisted of either 100 or 150 g rapeseed meal (double low variety)/kg diet. With phytase included at a rate of 1000 units/kg diet, an increased digestibility of calcium and phosphorous was observed. This was associated with an increase in liveweight gain, although the efficiency of feed conversion was not affected. Janocha *et al*. (2000) also observed that nutrient utilisation from rapeseed cake was increased when phytase was included in the diets of broilers. For monogastric animals, therefore, the efficiency of utilisation

of rapeseed products is increased (as is the case with cereals) by the addition of exogenous phytase to the diet. The observations of Park *et al.* (2000) with sheep fed dry-heat treated rapeseed meal would suggest that ruminant animals might also benefit from the addition of phytase if they are fed rapeseed products that have been heated during processing. The use of the enzyme Allzyme Vegpro (Alltech Biotechnology Center, Kentucky, US), however, had no effect on the digestibility or efficiency of utilisation of barley-based diets supplemented with canola meal fed to growing and finishing pigs (Thacker, 2001).

5.4.2. Iodine supplementation

Since the glucosinolates in rapeseed products result in impaired uptake of iodine by the thyroid gland, one logical means of addressing the constraints encountered by feeding rapeseed is to increase the iodine content of the diet. Schöne *et al*. (2001) fed sows diets containing either no rapeseed, whole rapeseed or rapeseed cake. The rapeseed cake was included at two different rates in the diet. The diet containing full fat rapeseed had a glucosinolate concentration of 1.9 mmol/kg, while the corresponding values for the diets containing rapeseed cake were 2.1 and 4.2 mmol /kg. These diets were fed with or without a supplement of 600 µg iodine/kg diet. The inclusion of rapeseed products in the diet reduced the concentration of iodide in the sows' milk and the piglets' sera. This effect was reduced by the supplementation of iodine in the diet. Similar observations have been made in cows fed diets containing rapeseed meal, with different concentrations of iodine in the diet (Hill, 1991). The products of glucosinolate hydrolysis have different effects on the thyoid gland, and the supplementation of iodine in the diet is only likely to ameliorate a situation in which iodine uptake by the thyroid gland is inhibited. This is the case with thiocyanates, which are derived from sinalbim and neoglucobrasssim. Animals fed rapeseed products that have a high concentration of these particular glucosinolates may respond positively to the addition of iodine in the diet. However, it was noted by Spiegel and Blum (1993) that it was the reduced feed intake, and not hypothyroidism, that was the main cause for reduced performance by pigs fed large quantities of glucosinolate from rapeseed products.

5.4.3. Feeding system

When rapeseed meal, particularly those with a low glucosinolate concentration, are included in compound concentrate feeds as the sole source of protein, intake by ruminant animals does not appear to be adversely affected (Hill, 1991). Very sensitive tests investigating the acceptability of rapeseed meal by calves and lambs suggested that calves in particular found rapeseed meal less acceptable than soyabean meal, but this differentiation was less marked if the rapeseed had a low glucosinolate content (Stedman and Hill, 1987). However, even in these situations, there was little difference in feed intake measured over a longer period (24 h compared with 30 or 60 min). It is possible that in situations where large quantities of feed need to be consumed in a short time (eg. during parlour milking by dairy cows) that intake may be reduced if compound feeds contain rapeseed meal rather than soyabean meal. In situations where animals are required to gain

weight at the maximum rate (for example with early-weaned calves and lambs), it is also possible that performance may be affected by the inclusion of rapeseed meal. However, no data were found to support or contradict these suggestions (Hill, 1991). In the case of dairy cows, any such problem with the parlour feeding of concentrates could be overcome by altering the feeding system. With the increasing use of systems that feed concentrates out of the parlour (in out of parlour feeders, or incorporated in total mixed rations), such situations are less likely to arise. However, there may be an issue regarding the use of the 'straight' feed. When rapeseed meal was fed alone it was much less acceptable that sunflower meal and this had an adverse effect on the growth of the lambs fed this meal (Hill, 1991). However, the glucosinolate content of rapeseed meal has declined since this study was undertaken. It is also true that, while selection of individual feeds within a total mixed ration is certainly practised by livestock, the incorporation of rapeseed meal as a straight into a mixed diet is unlikely to have such a dramatic effect on intake and performance.

6. CONCLUSIONS

Full fat rapeseed and rapeseed meal from double low varieties of oilseed rape are valuable feeds for all classes of livestock. Genotype, agronomy, processing technique, and any subsequent treatment the feeds are exposed to may affect their nutritive value. There is, however, little evidence that the yellow coated 'triple low' varieties of rapeseed are any more digestible (by any class of livestock) than the more traditional brown coated varieties. Similarly differences in the chemical composition and nutritive value of large and small seeds are small, and unlikely to be of any practical significance. However, there is a dearth of information on the nutritive value of modern UK varieties of rapeseed, which makes demonstrating their possible superiority over older varieties difficult. As the glucosinolate content of rapeseed declines, it seems reasonable to suppose that the problems that have been encountered in the past when rapeseed products were fed will be overcome. However, limitations on the use of rapeseed products are often ones of perception, and the result of historical problems when rapeseed products with much higher glucosinolate contents were fed to livestock.

The anti-nutritive factors in rapeseed products that are of importance are the glucosinolates and (in the case of laying birds) sinapine. The concentrations of both of these factors vary with rapeseed variety, but agronomic factors also have an influence. Reducing the inputs of N and S to rapeseed will result in a decreased total concentration of glucosinolates in the seed, and in a decreased proportion of goitrin (the most goitrogenic of the glucosinolates) in the glucosinolate fraction. Sinapine can cause a problem of a fishy taint in brown eggs, and at present one of the main producers of brown eggs in the UK will not accept eggs from birds that have been fed any rapeseed. A consistent reduction in the sinapine content of rapeseed, or a reliable means of eliminating its activity, will need to be demonstrated before the use of rapeseed products in the diets of laying hens can be increased.

Double low varieties of rapeseed meal can generally be used as freely as soyabean meal in the diets of ruminant animals. Rapeseed meal has been included in the diets of dairy cows at a rate of 360 g/kg concentrate without encountering any problems, although the norm is still to limit the inclusion rate to 150 g/kg concentrate. More research needs to be done to determine whether the slight negative effect that has been observed of rapeseed meal on the fertility of heifers is real. Feed intake may be limited when large quantities of rapeseed products are fed to pigs and poultry, but the inclusion rate of (low glucosinolate) rapeseed meal can be up to 150 g/kg in the diet of finishing pigs and 200 g/kg in the diet of broilers. This should be limited to 120 g/kg in the diet of sows and, as has been mentioned before, the inclusion of any rapeseed meal is banned in the diets of some laying hens.

The evidence from the literature suggests that seed variety and processing will have relatively little effect on the nutritive value of rapeseed, and therefore manipulating these will not have much impact on the potential inclusion rate of rapeseed products in livestock diets. The treatment of full fat rapeseed and rapeseed meal, however, might affect their inclusion rate. Full fat rapeseed fed to pigs needs to be both heated and ground to optimise digestibility. Full fat rapeseed fed to broilers needs to be ground to a particle size of $\leq$0.56 mm if its nutritive value is to be realised, but the benefit of subsequently heating this product has not been demonstrated. The advantage of feeding full fat rapeseed to ruminant animals is that the seed provides a degree of protection to the rumen environment from the oil in the seed. Similarly, the oil is protected from rumen biohydrogenation. Heat-treating the seed may increase this protection still further, but may well result in overprotection so that the availability of the oil to the animal is reduced. The heat may either increase or decrease the rumen degradability of protein, depending on the effect of the heat on the fat globules in the seed. The vitamin E intake of animals fed full fat rapeseed may need to be increased to prevent oxidation of the meat and milk fat.

The most effective means of treating rapeseed meal to increase its nutritive value is to extract its glucosinolates in warm water. However, this will not necessarily result in any obvious improvement in animal performance. Heat-treating the rapeseed meal can result in improved performance in pigs and poultry, and at temperatures up to 125^0C it may decrease rumen protein degradability without affecting intestinal protein digestibility. However, there are many situations in which such treatment has not resulted in any actual improvement in the performance of ruminant animals.

The use of rapeseed products in the diets of laying hens may be increased by the development of varieties with a very low sinapine content. Full fat rapeseed for pigs and poultry needs to be ground to optimise its digestibility, and there may be some benefit in extracting the glucosinolates from rapeseed products in warm water to reduce the inhibitory effect these compounds have on the voluntary feed intake by livestock. Such interventions may help to increase the contribution that rapeseed products can make to livestock production, and provide an alternative market for rapeseed grown in the UK.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

In the light of this review, it is recommended that the following areas require further research to bring about an increase in the utilisation of rapeseed products as feeds for farmed livestock:

1. Characterisation of the nutritive value of full fat rapeseed and rapeseed meal produced from modern genotypes of rapeseed grown in the UK. This would involve estimates of rumen protein degradability, measures of protein digestibility in ruminant and non-ruminant animals, as well as an investigation of any differences in the amino acid and fatty acid composition between different genotypes. It is possible that some lines could be selected that would markedly improve the protein quality of rapeseed products for livestock nutrition, or alternatively result in an improved fatty acid composition of animal products.

2. The effects of processing and treatment on the nutritive value (in particular protein quality) of rapeseed products should be investigated. A project funded by HGCA that is currently underway is researching the effects of processing and treatment on the nutritive value of rapeseed meal, but the effect of treatment on the nutritive value of full fat rapeseed should also be examined.

3. Research on developing means of decreasing the sinapine content of rapeseed products would enable rapeseed to be used more extensively in the diets of laying hens. The sinapine content may be reduced either through selective breeding, or through treatment of the full fat rapeseed or rapeseed meal. Both avenues should be investigated.

4. The nutritive (and potentially anti-nutritive) value of rapeseed meals derived from varieties of oilseed rape with a high concentration of erucic acid should be established, as the development of oilseed rape for industrial uses may result in an increased availability of this product.

5. The question as to whether rapeseed meal has a negative effect on the fertility of heifers needs to be addressed. This will require detailed metabolic studies to ascertain what endocrine response there may be to the inclusion of rapeseed in the diet. This should then be followed up with a large-scale study using many heifers to determine the real impact of rapeseed on heifer fertility.

6. The use of relatively high concentrations of rapeseed in the diets of livestock could be demonstrated in a series of feeding experiments at different research centres and other farms to illustrate to farmers and their advisers the safe use of rapeseed products in livestock diets. This technology transfer exercise may help to overcome the limits that are set on the amount of rapeseed that is included in the diets of livestock.

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