RAPESEED MEAL for LIVESTOCK and POULTRY

— A REVIEW

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RAPESEED MEAL for LIVESTOCK and POULTRY

–A REVIEW

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PREFACE

Rapeseed was first grown commercially in western Canada in 1942 as a war measure to supply oil for lubrication of marine engines. Production has expanded rapidly so that rapeseed now represents an important crop for Canadian farmers. A major byproduct of oil extraction is rapeseed meal. In recent years there has been a conversion from expeller extraction of the oil to prepress-solvent or solvent extraction. As a consequence commercial rapeseed meals are not subjected to high temperatures during processing. Research suggests that these meals are comparable to soybean meal as a protein supplement for most classes of livestock and poultry.

The increased production of rapeseed, the expanding research in breeding of new rapeseed varieties, the changes in processing methods and increased knowledge of nutritional properties of the meal have made it imperative that information on the nutritional value of rapeseed meal should be compiled and evaluated under one cover. It is hoped that this review will allow feed processors and livestock feeders to make optimum use of rapeseed meal. The review should also point out to research workers the areas where information on rapeseed meal is limited.

Each chapter of this review is intended to be a complete entity which may be read without extensive reference to previous or subsequent chapters. Therefore there is a certain amount of overlapping to allow an individual author to deal with the subject matter in breadth as well as depth. As in any collaborative monograph, helpful suggestions, ideas and criticisms have been made by numerous people. The editors and authors wish to acknowledge, with thanks, their indebtedness to these unnamed collaborators.

Edmonton, Alberta, Canada
May 15, 1965

John P. Bowland, Chairman
Editorial Committee

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CHAPTER 1. RAPESEED BOTANY, PRODUCTION AND UTILIZATION

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Botany

Origin

The origin and history of *Brassica napus* L. and *Brassica campestris* L. is not well documented, although closely related species were well known in ancient times. Black mustard, *Brassica nigra* L., was referred to by early Greek writers and was cultivated in Europe in the thirteenth century (137). Cabbage and kale (*Brassica oleracea* L.) were used by the Greeks and Romans before the Christian era (23). The English word rape, as it applies to the oilseed forms of *B. napus* and *B. campestris,* is derived from the Latin word rapum, meaning turnip. Plants of *B. napus* L. var. *oleifera* are called rape, colza and raps in Europe, and Argentine rape in Canada. In Europe, *B. campestris* L. var. *oleifera* is known as turnip rape, navette and rübsen, whereas in Canada it is called Polish rape. In this chapter the European common names of rape and turnip rape are used, and refer specifically to oilseed forms of *B. napus* and *B. campestris,* respectively. Collectively the two species are referred to as "rapes" or "rapeseed". The earliest direct references to the oilseed rapes are found in ancient Indian Sanskrit writings of 2000 to 1500 B.C. (121). Singh (121) considered the Indian *B. campestris* variety Yellow Sarson to be the oldest of the various rapes and mustards found in that Asiatic subcontinent.

The wide commercial distribution of *B. campestris* as a weedseed and vegetable has tended to obscure its center of origin. Sinskaia (123), after a study of the diversity of forms found within this species in Europe and Asia, suggested that the center of origin of both turnip and turnip rape would ultimately be located in Asia. On the other hand, she noted that all cultivated Asian turnip rape is of the summer form, and thus concluded that winter turnip rape must have originated under a maritime climate such as the Mediterranean. In contrast, Andersson and Olsson (6) recognized three main geographical groups: Asiatic, Mediterranean and West European. Certainly the Indian Sarson varieties are distinct from the European forms (90, 121, 127, 128). Probably the Indian and European varieties were separated at an early stage in the development of the species and evolved along different lines.

B. napus was thought to have its origin in the Mediterranean area (123). However, this theory was formed before the genome constitution of *B. napus* was known. It is now known that *B. napus* is an amphidiploid resulting from crosses between plants of *B. campestris* and *B. oleracea* (135). Thus, *B. napus* has probably originated at many different times and locations where plants of the two basic species grew in proximity (90).

Domestication

Domestication of rape and turnip rape has occurred whenever the economic value of the locally adapted weed was recognized (123). In Europe, cultivation of rape and turnip rape on a field scale was not common until the thirteenth century. However, even before this time, seed was gathered from wild forms and the oil extracted and used for illumination and soap making. Field cultivation appeared first in Belgium and from there spread to Holland and North Germany and, in the sixteenth century, to South Germany. Apparently both species were grown since seed of both types has been found in grist mills of old German settlements (12). In the nineteenth century the cultivation of rapeseed extended eastward into Switzerland, Poland and Russia, and northward into Denmark and Sweden (12, 146). At this time, approximately 3,000 to 4,000 hectares (1 hectare=2.471 acres) of rape were grown in Sweden (3), and in 1866, 15,500 hectares in Denmark (69). In India the ancient custom of sowing summer turnip rape called Sarson and Toria and the Indian mustard, Rai, in mixture with other crops such as wheat, barley and gram, is still practiced as a protection against total crop failure (121). The history of rapeseed cultivation in China is obscure. Old Japanese literature indicates that rape was introduced to Japan 2,000 years ago directly from China or through the Korean Peninsula. Oriental forms of *B. campestris,* indigenous to Japan, were used as vegetables as early as the sixth century but not until the fourteenth century was the seed pressed for lamp oil. In the seventeenth century the Portuguese and Spanish traders introduced fried foods to the Japanese. In this way rapeseed oil was established as the traditional edible oil of Japan (59, 74). North and South America adopted oilseed rape as a cultivated crop prior to and during World War II.

Taxonomy and Genome Relationships

The Cruciferae family to which the genus *Brassica* belongs, contains many important crop plants and weeds (Table 1.1). In the domestication of the *Brassica* genus man has utilized and modified through selection almost every plant part. The occurrence of similar forms in more than one *Brassica* species resulted in considerable misclassification by early botanists as they separated species solely on morphological characters. Thomas and Crane (130) noted that it was less confusing, in *Brassica,*

Table 1.1. Nomenclature and genome relationships of some *Brassica* species and related genera

Species name	Common synonym	Chromosome no. (n) and genome	Common names		
			English	French	German
B. campestris L.					
ssp. *oleifera* (Metzg.) Sinsk. f. *annua*	*B. rapa* ssp. *oleifera* Metzg.	10 aa	Summer turnip	Navette d'été	Sommerrübsen
ssp. *oleifera* (Metzg.) Sinsk. f. *biennis*			Winter turnip rape	Navette d'hiver	Winterrübsen
ssp. *eu-campestris* (L.) Olsson	*B. campestris* L.		Bird rape		Wilder Rübsen
			Wild turnip rape		Wilder Rübenkohl
ssp. *sarson* Prain	For list see Singh (121)		Yellow and brown sarson		Gelbsamiger Sarson
ssp. *dichotoma* (Roxb.) Olsson	*B. napus* ssp. *dichotoma* Prain		Toria	Toria	Toria
ssp. *chinensis* (L.) Makino	*B. chinensis* L.		Chinese mustard		
			Pe-tsai		Petsai
ssp. *pekinensis* (Lour.) Olsson	*B. pekinensis* (Lour.) Rupr.		Celery cabbage		
ssp. *nipposinica* (Bailey) Olsson	*B. nipposinica* Bailey		Curled mustard		
ssp. *rapifera* (Metzg.) Sinsk.	*B. rapa* L.		Turnip	Navet-rave	Rübe, Wasserrübe
B. tournefortii Gouan			Wild turnip		Wilde Rübe
B. nigra (L.) Koch		8 bb	Black mustard	Moutarde noire	Schwartzer Senf, Senfkohl
B. oleracea L.					
ssp. *acephala* DC.		9 cc	Kale	Chou vert	Grünkohl
ssp. *botrytis* L.			Cauliflower	Chou-fleur	Blumenkohl
ssp. *capitata* L.			Cabbage	Chou potager	Kopfkohl
ssp. *gongylodes* L.			Kohlrabi	Chou-rave	Kohlrabi
ssp. *italica* Plenck			Broccoli	Brocoli	Brockoli
ssp. *sylvestris* L.			Wild cabbage	Chou sauvage	Wildkohl
B. juncea (L.) Coss	*B. cernua* Forbes & Hemsl.	18 aabb	Brown, Oriental, leaf or Indian mustard		Sarepta-senf
B. napus L.					
ssp. *oleifera* (Metzg.) Sinsk. f. *annua*	*B. napus* L. *annua* Koch	19 aacc	Summer or Argentine rape	Colza de printemps	Sommerraps Ölraps
ssp. *oleifera* (Metzg.) Sinsk. f. *biennis*	*B. napus* L. *biennis* (Schuebl. & Mart.) Reichenb. *B. napella* Chaix.		Winter rape	Colza d'hiver	Winterraps
ssp. *pabularia* (DC.) Reichenb.			Rape-kale	Chou à faucher	Schnittkohl
ssp. *rapifera* (Metzg.) Sinsk.	*B. napobrassica* (L.) Mill.		Rutabaga, swede	Chou-navet, navet de Suède	Kohlrübe
B. carinata Braun.		17 bbcc	Abyssinian mustard		
B. hirta Moench	*Sinapis alba* L.	12 dd	White or yellow mustard	Moutarde blanche	Weisser Senf Echter Senf
B. kaber (DC.) L.C. Wheeler	*Sinapis arvensis* L.	9 ss	Charlock	Moutarde des champs	Ackersenf
Eruca sativa Mill.		11 ee	Rocket salad	Roquette	
Raphanus sativus L.		9 rr	Radish		
Camelina sativa Crantz.		20	Camelina, false flax		
Crambe abyssinica		45	Crambe, Abyssinian kale		

to use common than Latin names. However, in recent years there has been general agreement on the nomenclature of major groups, although opinions are still divided on the *B. campestris* complex (91, 127, 128, 143).

The genetic and cytological relationship between the two rape species and their close relatives was established by Morinaga (77, 78, 79, 80, 81, 82), Sasaoka (115), and U (135). They made interspecific crosses and analyzed cytologically chromosome conjugation at metaphase I. Morinaga (82) proposed that the species of *B. napus, B. juncea* and *B. carinata,* which have higher chromosome complements, were amphidiploids derived from the monogenomic species *B. nigra, B. campestris* and *B. oleracea.* The accuracy of this scheme was corroborated by the synthesis of existing species. Fertile plants of *B. napus* were formed from crosses between *B. campestris* and *B. oleracea* (57, 64, 68, 89, 95, 98, 111, 112, 135). Similarly, plants of *B. juncea* were formed from crosses between *B. campestris* and *B. nigra* (56, 72, 93, 107), and plants of *B. carinata* from crosses between *B. oleracea* and *B. nigra* (57, 73, 75). There also is cytological evidence that the three elemental genomes are themselves secondary polyploids, probably originating from a common ancestor with a basic chromosome number of 5 or 6 (2, 29, 30, 60, 72, 109, 110, 120). The genera *Sinapis, Eruca* and *Raphanus* also may have evolved from this same progenitor (58, 60, 72).

Morphology

Annual and biennial forms of both species are cultivated. *B. napus* and the Yellow Sarson variety of *B. campestris* are largely self-fertile. Other *B. campestris* varieties are self-incompatible. Under field conditions the rapes are cross-pollinated by wind and insects (94). Seeds mature 30 to 40 days after fertilization. The seed is primarily embryo, surrounded by a thin layer of endosperm. The cotyledons are conduplicate and contain 30 to over 50% oil. Most of the seed oil is laid down in the last 20 days of maturation (5, 76, 104, 122). The thin seed coat may be black to reddish brown or yellow and its reticulations are used for species identification (20, 84).

Adaptation

The rapes are adapted to temperate regions and also to subtropical areas of India, Japan and Mexico where they are used as winter or cool season crops. Wild forms of *B. campestris* are found from the British Isles east to Japan and from northern Norway south to the Sahara, Pakistan and the northern provinces of India (123). In more recent times, distribution has been extended to North and South America, Australia and New Zealand. In contrast, *B. napus* is not cultivated in central Asia (121, 123) and the northern dispersion is more restricted in Sweden and Canada (51, 69). Schwarze (117) in Germany states that high temperatures

during ripening favor high oil content in rape, provided there is sufficient moisture. In Canada, however, higher oil contents are obtained in more northerly latitudes (22). Under controlled moisture and day length Siemens (119) found significantly higher oil content in *B. napus* seed matured under 12.7 C day temperature than under 18.3 or 23.9 C. Highest yields of seed are obtained on deep, well-drained, loamy soils (6, 121). However, rape is a recommended crop for saline areas in Holland (1, 102) and peaty soils in Sweden and Canada (51, 69). Thus, crop adaptation is extensive and production depends more on the relative availability and cost of other vegetable oils than on soil and climatic conditions.

Types and Varieties

Of the two species, *B. napus* has a greater potential yield of seed and oil than *B. campestris.* Where winter forms can be grown they are more productive than the summer types (3, 51, 69).

In Europe, three basic groups of winter rape are found. The Janetzke variety is intermediate between the hardy and non-productive East European group and the moderately hardy but high-yielding mid-European types. Lembke's winter rape, from which the improved varieties of Matador, Vestial, Alsace and Oleor have been bred, is characteristic of the mid-European group. The nonhardy West European group is represented by Mansholt's Hamburger (6).

Winter turnip rape is grown primarily in Finland, middle Sweden, and Eastern Europe where greater hardiness is essential. In *B. campestris*, as with *B. napus,* hardy material is found in Eastern Europe, but potentially higher yielding germ plasm of moderate hardiness originates in Middle Europe. Such varieties as Duro, Gruber and Janetzke are intermediate between the moderately hardy Lembke and the hardy Rapido winter turnip rape varieties (6). Regina II, Janetzke and Cresus varieties of summer rape are used in Europe as alternate crops when winter seedings fail or where winter forms will not survive. Where the summer growing season is short, the summer turnip rape varieties Arlo and Bele are important.

In the Western Hemisphere, Chile grows both Matador winter rape and Regina II summer rape (103). In Canada, only the summer forms are grown for seed, as even the most winter hardy turnip rape varieties will not consistently survive on the open plains of western Canada. The turnip rape varieties Arlo and Echo occupy 70 to 80% of the rapeseed acreage of western Canada. Although they have only 80 to 85% of the yield potential of the Canadian *B. napus* varieties, Nugget, Tanka and Golden, they are preferred because of their 10- to 14-day earlier maturity (51, 114).

Production in Japan, as in Europe, is almost exclusively of winter rape. Widely grown varieties such as Norin[1] No. 6, 14 and 17, were bred from

[1] Norin stands for Agriculture–Forestry.

B. napus material, but other important varieties such as Michinoku- and Murasaki-natane[2] were derived from *B. napus* × *B. campestris* crosses (67, 83, 118).

In central Asia, annual *B. campestris* forms such as Toria and Sarson are grown exclusively. In China, Pakistan and India little distinction is made between these turnip rape forms and *B. juncea* as all are grown for their oil (32). There are marked contrasts in growth habit, seed size and color, pod size and shape, and oil composition between European turnip rape and the Asian group (91, 121). Within the Asian group the main difference between Toria and Sarson is in maturity, with Toria being early. Improved Indian varieties include Yellow Sarson No. 151, 10, 40 and 13; Brown Sarson BSG; and Toria No. 7, 9 and Abhar (101, 121).

Production

Among the edible vegetable oils, rapeseed ranks fifth in total world tonnage, being exceeded by soybeans, peanuts, cottonseed and sunflowers. China, India and Pakistan produce about two-thirds of the world's rapeseed (Table 1.2). Chinese production, primarily centered in the Yangtze Valley, has been markedly lower in recent years. However, domestic demand in Asian countries usually exceeds supply and thus their production has little effect on the world vegetable oil price structure (62).

Rape and sunflowers are the only edible vegetable oil crops that can be produced effectively in northern parts of Europe, Asia and Canada. Major production shifts have occurred in Europe and the Americas since World War II. Increased production in Poland, Sweden and Finland resulted at least partially from the political need to be self-sufficient in vegetable oils in case of war (3, 113). Most European countries control production through a guaranteed price or by regulating the amount of rapeseed oil that must be used in edible products. In Canada, economics alone resulted in the establishment of a rapeseed industry following World War II since rapeseed proved to be an alternate crop to spring wheat in northern regions of the Canadian prairies.

In most countries domestic rapeseed consumption exceeds production. Only one-ninth of world production enters export channels (136). In recent years Canada has exported more rapeseed than all other countries combined. Japan, Italy, Netherlands, Algeria, France and West Germany have been the main customers. French exports have been principally to Algeria and Italy, while seed from Denmark and Sweden has gone to Italy, France and Algeria. Sweden and France are the largest exporters of rapeseed oil, with West Germany, Italy and United States the most consistent importers (32). Accurate statistics of trade in rapeseed meal are not readily available. However, it has been estimated that the major producing countries have had annual exports of approximately 30,000 metric tons of meal in the period 1958 to 1962 (31).

[2] Natane stands for rapeseed.

Table 1.2. World production of rapeseed 1930-39; 1945-59; 1962; and the average exports of rapeseed and oil, 1958-62 (32)

Country	Production, 000 metric tons*						Exports, 000 metric tons 1958-62	
	1930-34	1935-39	1945-49	1950-54	1955-59	1962	Seed	Oil
				Asia				
China	2,227	2,102	(3,100)	(2,854)	(933)	(935)	11	7.5
Formosa	—	—	—	—	1	10	—	—
India†	1,264	969	1,001	866	956	1,259	—	0.2
Pakistan†				277	312	355	—	—
Japan	86	118	20	210	272	329	—	0.1
Turkey	—	—	—	—	2	4	—	—
				Europe				
Austria	—	2	6	6	8	9	—	—
Belgium	—	—	4	3	1	—	—	—
Bulgaria	7	11	1	(3)	2	6	1	—
Czechoslovakia	—	10	13	(29)	49	47	—	—
Denmark	—	—	—	13	5	50	14	0.1
Finland	—	—	—	12	14	7	—	—
France	18	11	86	135	130	153	34	12.1
Germany, West	17	86	104	52	47	112	—	4.8
Germany, East				243	166	159	—	0.4
Hungary	9	9	2	(2)	2	4	—	—
Italy	—	2	14	11	9	10	—	—
Netherlands	—	4	22	21	15	10	8	0.8
Poland	30	53	(48)	(95)	105	349	1	—
Romania	26	42	2	(5)	7	—	—	—
Sweden	—	—	37	152	139	126	30	10.1
Switzerland	—	—	—	5	8	12	—	—
Yugoslavia	4	11	4	7	6	2	—	—
				Africa				
Ethiopia and Eritrea	—	—	—	—	19	23	2	—
				Western Hemisphere				
Argentina	—	26	18	2	—	—	—	—
Canada	—	—	12	7	121	129	129	0.3
Chile	—	—	—	—	18	46	—	—
Mexico	—	—	7	(7)	7	10	—	—
United States	—	—	—	—	2	1	—	—

*Figures in parentheses are estimates only. Annual production of 18,000 metric tons has been reported for the U.S.S.R. for 1935-39 (54), but recent data on Russian production and acreage are not available.

†Includes rape and mustard.

Utilization

Forage Crop

Rape produces an abundance of succulent fodder (66). Some winter and spring rape varieties are used as fodder crops for cattle throughout Europe. In Swedish yield trials, Garton's Early Giant winter rape produced an average dry matter yield of 5,925 kg per hectare (5,273 lb per acre), of which 14.9% was crude protein and 18.6% crude fiber (96). In Britain, kale (*B. oleracea* var. *acephala*) and rape (*B. napus*) are the main sources of fall and winter fodder (40). A cross of *B. campestris* × *B. oleracea* resulted in an excellent fodder crop for Japan (65, 141), and *B. campestris* varieties are used for fodder in India (121). Forage rape is the most important green fodder crop in New Zealand for fattening lambs (85). In North America, forage rape is used primarily as a hog pasture and produces rapid, economical gains (44).

Oilseed Crop

Meal.—Rapeseed crushed in modern mills yields approximately 40% oil and 50% oil meal or oil cake, the remainder being moisture. The major use of the oil meal is as a high protein feedstuff which will be discussed in following chapters. However, in Japan the major meal use is as a high nitrogen fertilizer for over 8,000 hectares (19,284 acres) of tobacco. At least one-half the 100 to 150 kg per hectare (89 to 134 lb per acre) of nitrogen required by Japanese tobacco is supplied through the application of 800 to 1,250 kg of meal per hectare (712 to 1,112 lb per acre). The balance of the nitrogen is usually supplied as urea or ammonium phosphate in compound fertilizers, although some growers continue to use rapeseed meal exclusively (129, 142). Rapeseed meal fertilization is considered indispensable to production of high-quality tobacco in high rainfall districts since the slow nitrogen release from the meal corresponds to the uptake requirements of tobacco and reduces nitrogen losses due to leaching (142). Low-quality meals and meals containing appreciable amounts of mustard are also used as a general purpose fertilizer in Europe and India.

Oil.—Chemical composition: Crude rapeseed oil consists primarily of fatty acid glycerides, together with minor components such as the free fatty acids, chlorophylls, phosphatides and sterols. The minor constituents are removed on refining, bleaching, and deodorizing, but have an important bearing on the color and keeping qualities of the crude oil. When chlorophylls are present in large quantity they may be difficult to remove. The amounts of minor constituents depend primarily on conditions during seed development, harvest and handling. Tocopherols, important as antioxidants and as a vitamin E source, are also found in the oil, but the factors influencing the amounts have not been intensively studied (8).

The fatty acid composition of a vegetable oil determines its suitability for industrial or edible purposes. However, the refractive index and iodine number of rapeseed oil is not a reliable index of the fatty acids present.

Craig and Wetter (38) report two rapeseed samples with iodine numbers of 104.6 and 104.1 which contained 40.4 and 22.4% erucic acid, respectively. This apparent anomaly results from the variation in degree of unsaturation and carbon chain length found in the oil of both species (Table 1.3). Extreme erucic acid values of 57 to 61% have been reported in the Indian Sarson varieties (48, 63, 121). Singh (121) reports only 1% linolenic acid in these Indian varieties. However, similar seed analyzed by gas chromatography in our laboratory contained 8 to 9% linolenic acid (48). In its present composition rapeseed oil is a dual-purpose oil. The high percentage of oleic and erucic acids gives it important industrial uses, while the relatively low content of linolenic acid makes it suitable as an edible oil.

Industrial uses: In early times rapeseed oil was used primarily for illumination and soap making. As the demand for products for these uses decreased, marine engines were developed which required a lubricant that would cling to metal surfaces when washed by steam and water. Blends of both refined and blown rapeseed oil proved superior to mineral oil for this purpose. In recent years, a general purpose grease has been developed in which rapeseed oil replaces castor oil. This grease is now marketed in Canada (55, 86, 99). The oil is also used in conjunction with tallow as a lubricant for cold rolling steel (21, 138) and in the manufacture of soft soap used in sizing cloth (121). The erucic acid fraction has special industrial applications such as the lubrication of jet engines, the manufacture of plastics, the making of erucic ethylene glycol polyester surface film to reduce evaporation from rice paddies, and as a flotation agent in potash mining.

Edible uses: Most of the oil produced today is used for salad and cooking oils, margarine, and shortenings. Thus nutritional aspects of rapeseed oil have been extensively investigated. Among digestibility coefficients

Table 1.3. Ranges, in percentages, of fatty acids in *B. napus* and *B. campestris* (8, 10, 35, 48, 54, 62a, 71 144)

Fatty acid*	Symbol	Percent composition	
		B. napus	*B. campestris*
Palmitic	C 16:0	2 – 4	2 – 3
Stearic	C 18:0	1 – 2	1 – 2
Oleic	C 18:1	9 – 24	14 – 26
Linoleic	C 18:2	13 – 16	12 – 18
Linolenic	C 18:3	5 – 12	7 – 12
Eicosanoic	C 20:1	7 – 15	8 – 12
Erucic	C 22:1	36 – 54	22 – 46

*Minor amounts (1% or less) of palmitoleic, arachidic, and docosadienoic are also present.

reported are 98 to 99% for man (43) and 77% for rats (42) (*see* Chapters 5, 6 and 7 for further information on digestibility). It is generally agreed that, when rapeseed oil makes up a substantial portion of the diet of the rat, food intake is reduced, growth is retarded, and life extended (19, 131, 132, 133). These effects have been attributed to erucic acid in the oil, but recent studies indicate that the low content of saturated acids, especially palmitic acid, may be the cause (14, 39). The effects of rapeseed oil and erucic acid on the adrenals and fertility of the rat have also been studied. It is now apparent that strains of rats differ in their reaction to diets containing rapeseed oil. The rats used by Carroll (24, 25, 27, 28, 87) exhibited reduced fertility and increased cholesterol level and size of the adrenals. However, the strain used by Beare (13, 15, 16, 17, 18, 19) reproduced normally and showed no effects on the absolute adrenal weight or proportion of adrenal weight to body weight when on rapeseed oil diets. In addition, when fed to rabbits, guinea pigs, chickens and dogs rapeseed oil had little or no effect on adrenal cholesterol (26). Wigand (140) reported that serum cholesterol levels in rabbits were reduced equally by rapeseed and corn oils.

Prospects of Crop Improvement

The opportunity for improvement of any agricultural crop is dependent on the genetic variation which exists within the crop and its close relatives, as well as the facility with which desirable characters can be recognized and fixed in the population. The variability evident in species of rape and throughout the *Brassica* genus, coupled with the ease with which the species may be crossed, suggests that there are great possibilities for improvement.

Breeding for Increased Seed and Oil Yield

The common aim of world rapeseed breeding programs is the development of strains that produce higher yields of seed with higher oil and protein contents. Numerous varieties have been selected from adapted sorts in recent years. However, little attention has been given to commercial hybrid seed, even though pollen-sterile individuals have been identified (6, 45, 68). Similarly, the use of X-irradiation as a breeding tool has not been extensive despite the success of Regina II summer rape which was selected from an irradiated population (4). Crosses between ecotypes and species have also been successful and hold considerable promise (6, 83, 90).

Polyploid breeding in oilseed rape and turnip rape has not been fruitful (96). Although tetraploid turnip rape plants were larger and more vigorous than the diploids, they were lower in fertility, seed yield and oil content (9, 106, 116). Despite intensive selection for seed and oil yield, tetraploid turnip rapes have not equalled the diploid varieties (50, 70, 100, 105).

Increased oil content in rapeseed results in a greater margin of profit to the crusher (88). Oil content varies widely with year, location, maturity at harvest, soil fertility and variety. Despite this, the heritability of this character, based on parent–progeny regressions, is considerably higher than for seed yield (6, 92). Thus selection for oil content has been very worthwhile, both in Sweden (97) and Canada where increases of 1.3 to 4.0% in oil have been obtained in recent years (47). Unfortunately a high negative correlation exists between oil and protein content (126), and between oil content and seed size (92). The association is not complete however. Olsson (92) combined high oil and large seed by crossing summer and winter rape and, in Canada, the summer rape variety Tanka produces larger seeds which contain more oil and protein than seed of the Golden variety from which it was selected.

It would appear that the limiting factor in increasing oil content has been the number of samples that could be analyzed since percentage oil and seed yield are not correlated (92, 126). Recent developments of oil determination techniques, which can be applied to seed lots of less than 5 g will greatly facilitate selection work (33, 134). In particular, the adaptation to oilseed work of nuclear magnetic resonance (11, 34) and air pycnometer equipment (145), whereby small seed lots retain their viability during rapid analysis, provides the plant breeder with powerful tools.

Breeding for Oil Quality

Oil quality is an important characteristic as rapeseed oil competes directly with other oil crops on the vegetable oil market. Gas chromatography has given the plant breeder rapid and accurate means of measuring oil quality (36, 37, 53). Wide variation in fatty acid composition is present within and between species (8, 38, 48, 49, 124, 125), but sufficient information is not available from industry and nutritional studies to predict accurately the ideal fatty acid composition. However, for human consumption, as well as improved keeping qualities and extended versatility of the oil, it would appear desirable to reduce erucic, eicosanoic, and linolenic acids to zero, and at the same time raise the level of linoleic acid while retaining the low content of saturated acids. Alternatively, since erucic acid has important industrial uses this component could be maximized in some varieties.

Considerable progress towards producing both types of oil has been made in Canada (48, 49, 125). Further, the biosynthetic pathway (52) and genetic control of erucic and eicosanoic acids synthesis has been determined (46, 53, 61, 124). Breeding material now under investigation, in lines containing no erucic acid, indicates the existence of genotypes that produce lower amounts of linolenic acid and greater amounts of linoleic acid (Table 1.4).

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Table 1.4. Fatty acid composition of improved oil selections in comparison with present varieties Golden and Arlo (48)*

Species and variety	Fatty acids, percent						
	C 16:0	C 18:0	C 18:1	C 18:2	C 18:3	C 20:1	C 22:1
B. napus							
Golden	3.3	1.1	18.6	14.0	7.8	13.4	41.8
Nugget	3.3	1.5	22.8	12.2	*5.4*	14.2	40.6
Zero erucic	4.7	1.8	*63.3*	*20.0*	8.9	*1.3*	*0.0*
B. campestris							
Arlo	3.2	1.1	26.6	17.5	8.8	11.8	31.0
Yellow Sarson	1.8	0.8	11.7	10.5	8.3	5.9	*61.0*
Zero erucic	4.3	0.1	*54.8*	*31.1*	9.7	*0.0*	*0.0*

*Major changes in fatty acid composition in italics.

Breeding for Meal Quality

In some countries, limitations are imposed on the feeding of rapeseed meal to certain classes of livestock. These limitations stem from the presence of low molecular sulfur compounds in the seed, some of which may, when released through enzyme action, cause metabolic disturbances in the animal. The nature and possible effects of these isothiocyanate and oxazolidinethione compounds will be discussed in detail in the following chapters. The problem they present may be eliminated either through modified processing methods or by plant breeding. In Canada, a new processing method which destroys the enzyme myrosinase by cooking the crushed seed without addition of water has become available (108). The safest and most economical solution, however, is either to breed strains with little or no sulfur-containing glucosides in the seed, or to select lines which produce only harmless isothiocyanates upon glucoside enzyme hydrolysis. Unfortunately, little is known of the relative toxicity of the various isothiocyanates found in the *Brassica* genus. On the other hand, present studies indicate that it is possible to select for both quantity and type of isothiocyanates from variation that exists within and between species (7, 41, 139).

Unpublished data from the National Research Council and the Canada Agriculture Research Station at Saskatoon show that sulfur fertilization has a marked effect on the total content of these compounds in the seed, but that, regardless of the level of sulfur applied, some rape varieties are

consistently lower in total isothiocyanates. It also has been determined that seed of Yellow Sarson differs markedly from the Canadian *B. campestris* varieties in the type of isothiocyanates it contains, and that the isothiocyanates present and their ratio to one another are entirely dependent on the genotype of the maternal parent. Thus, since both the total amount and kind of compounds are largely under genetic control, breeding for meal quality improvement is feasible, provided an accurate and rapid means of quantitative and qualitative analysis is developed.

Summary

Oilseed rape (*Brassica napus* L. ssp. *oleifera*) and turnip rape (*B. campestris* L. ssp. *oleifera*) of the Cruciferae family are closely related to one another, to the mustards (*B. juncea, B. nigra* and *B. carinata*) and to cabbage and kale (*B. oleracea*). Indeed, *B. napus* is an amphidiploid resulting from crosses between plants of *B. campestris* and *B. oleracea*.

Domestication of rape and turnip rape appears to have occurred wherever the value of the seed oil was recognized. Rapeseed is adapted to temperate regions and as a cool season crop in subtropical areas. Only annual forms are grown in Central Asia and Canada, but in other countries both annual and biennial forms are cultivated. *B. napus* has a higher seed yield potential than *B. campestris* but *B. campestris* has a greater range of adaptation.

World rapeseed production is about four million metric tons annually, of which approximately 75% is produced and consumed in Asia. Rapeseed stands fifth in total world production among edible vegetable oils. Canada exports more rapeseed than all other countries combined. Sweden and France are the main exporters of rapeseed oil. Extraction in modern mills gives 40% oil and 50% oilmeal, the remainder being moisture. Most of the oil is used in edible products, such as margarine and shortenings, and salad and cooking oils. The oil also has widespread industrial uses. The meal is mainly used as a high protein feedstuff, although in Japan the primary use is as a fertilizer for tobacco. Some varieties of rape are important as fodder crops in Europe, New Zealand and to a lesser extent in North America.

Prospects for overall improvement are great. Significant increases in seed and oil yields have been made in recent years and new oil composition types have been selected. New processing methods have improved the quality of rapeseed meal and recent research indicates that the meal may be improved further through plant breeding. Rapid advances can be expected as new analytical and chemical techniques are applied to the extensive variation found within the rape species and their close relatives.

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CHAPTER 2. PROCESSING OF RAPESEED MEAL

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Introduction

The processing of rapeseed to obtain oil and meal is similar to that for other high oil content seeds, such as linseed. In fact, the initial processing of rapeseed in Canada was done in plants designed for the processing of flax. These were expeller pressing mills and since the oil was the more valuable product they were operated to obtain a maximum oil yield. This involved the use of high pressures and resulting high temperatures. The major market for the oil at that time was an industrial oil and the type of processing used did not materially affect the quality of the oil for this purpose. It did, however, have an adverse effect on the quality of the meal obtained. As the demand for the oil for industrial purposes decreased and interest in it as an edible oil increased, attention was turned to the effect of processing on the quality of oil for this purpose. Pressures and temperatures in the expellers were lowered and, although this meant leaving more oil in the meal, the quality of both the oil and the meal was improved. As it became evident that an expanding market existed for rapeseed oil as an edible oil a number of new processing plants were constructed. These all involved solvent extraction of the oil from the seed either directly or after a mild expeller press to remove a portion of the oil. The use of solvent extraction allows almost complete removal of the oil from the meal but under mild conditions to provide the quality desired in the products. This type of processing has supplanted the earlier expeller processing.

The purpose of this chapter is to describe briefly the various processes which are, or have been, used and the effect of these on the quality of rapeseed meal.

Types of Processing

Expeller Pressing

This is a mechanical process in which the oil is squeezed from the seed. Prior to pressing the seed is crushed in roller mills as the first step in breaking up the seed structure to allow a separation of the oil and meal. Many oil-bearing cells remain intact after crushing and the walls of these cells are made permeable to oil by the action of heat and moisture in the next step which is cooking. Cooking is usually carried out in

"stack cookers". These consist of a series of superimposed cylindrical steel kettles independently jacketed for steam heating. The crushed seed is agitated by a sweep-type stirrer in each kettle. Automatically operated gates provide a continuous progression of the seed down through the kettles. The top kettle is provided with spray jets for the addition of moisture and each of the lower kettles is provided with an exhaust pipe for removal of moisture. Normally oil seeds are moistened in the early stages of cooking and their moisture content reduced during cooking. For rapeseed the resident time in the cooker is approximately 30 min and the maximum temperature reached varies from 100 to 120 C (212 to 248 F).

The crushed, cooked seed then passes to the expeller or screw press. This is essentially a continuous cage press in which the pressure is developed by a rotating worm shaft. Extremely high pressures, in the order of 15,000 to 20,000 lb/inch^2 (1050 to 1400 kg/cm^2) can be built up in the cage or barrel through the action of the worm working against an adjustable pressure orifice or choke that constricts the discharge of cake from the end of the barrel. The interior of the barrel is made up of flat steel bars set edgewise around the periphery and spaced to allow the oil to flow between the bars while the cake is contained within the barrel.

The action of the worm in the barrel of the expeller generates not only pressure, but also heat. The barrel is, therefore, cooled either by circulating water through channels in the barrel or by cooling the expressed oil and flushing a portion of this back over the exterior of the barrel. In a well-operated expeller plant the oil content of the cake can be reduced to about 4%, but may range up to 6 or 7 percent. The cake issuing from the expeller is both hot and dry and water may be sprinkled on it at this point to reduce the temperature and increase the moisture. The cake is then ground and is ready for marketing.

Prepress plus Solvent Extraction

In this process a portion of the oil is removed from the seed by pressing with expellers and the remaining oil is then extracted with an organic solvent. The pretreatment of the seed and the expellers used for pressing are the same as described in the previous section. In this case, however, only 70 to 80% of the oil is removed by pressing. This requires much less pressure than when oil recoveries of over 90% are required in straight expeller pressing. As a result of the lower pressures much less heat is generated in the expeller barrels and the throughput of the expellers is greatly increased.

The cake from the expeller, containing 15 to 20% oil, is reground and conveyed to the solvent extraction section of the plant. By far the most common solvent used is a light petroleum fraction composed largely of normal hexane with a boiling range of 60 to 70 C (140 to 158 F). The object in solvent extraction is to remove as much of the oil as possible from the meal with a minimum of solvent. This is accomplished most

efficiently by continuous countercurrent extraction. A number of mechanical means have been developed for moving the seed mass and the miscella (solvent plus oil) in opposite directions with free intermixing and for effecting a final separation of the miscella and the marc (solvent-saturated meal). These mechanical systems include screw conveyors in an inclined tube or "U" tube configuration; bucket conveyors operating in a vertical or horizontal direction; screen paddles scooping the marc from one container to the next; and vertical baskets rotating in a horizontal plane. The end result is the same in all cases in that the meal discharged from the extraction unit is saturated with solvent and contains around 1% of lipid.

The solvent is stripped from the meal in desolventizers which are similar to the stack cookers described in the section on expeller pressing. The bulk of the solvent is flashed from the meal in the top kettles. Live steam is introduced in the middle kettles to remove the remaining solvent and the meal is dried in the bottom kettles. At this stage the meal is solvent free, contains around 1% lipid, has a moisture content of 10 to 12% and is ready for marketing.

Direct Solvent Extraction

Normally high oil content seeds such as rapeseed are not directly solvent extracted as they tend to disintegrate into fine particles when placed in solvent. These fine particles cannot be handled successfully in the usual solvent extraction equipment. Recently a process known as "Filtration-Extraction" (8) has been developed which overcomes this problem and, as far as is known, is the only process that has been applied to the direct solvent extraction of rapeseed. The crushed, cooked seed is fed continuously into a horizontal, cylindrical tank and conveyed down its length as a slurry with miscella and slowly agitated to accomplish maximum extraction of the oil with minimum disintegration of the meal. The slurry is laid down on a horizontal rotating filter leaving the marc on the pan in a layer about 5 cm thick. As the filter rotates, the cake is washed; first with concentrated miscella to remove fines; then with two washes of decreasing oil content miscella; and finally with pure solvent. The marc is continuously removed and conveyed to the same type of desolventizing equipment as described in the previous section. The meal from the desolventizer contains about 1% lipid and 10 to 12% moisture, as in the case of prepress plus solvent extraction, and is ready for marketing.

Effect of Processing Variables on Meal Quality

One obvious effect of the method of processing on the quality of meal is the amount of oil left in the meal. As noted in the previous sections, in processes involving solvent extraction the residual lipid in the meal is reduced to 1% whereas in straight expeller-pressed meals this may vary from 4 to 7 percent. For a meal with 40.0% protein on an oil free basis, the

protein content with 1% oil would be 39.5% and with 7% oil 37.2 percent. In addition to this drop in percent protein the presence of 7% oil appreciably affects the energy–protein ratio of the meal and this may be a factor in evaluating the meal for animal nutrition.

Processing also affects the quality of the protein. Heat and moisture involved in processing result in denaturation of the protein and may also cause destruction of some of the more labile amino acids. Also of importance in the case of rapeseed meal is the effect of processing on the thioglucosides which are present in the seed.

Effect of Processing on Protein Quality

There is extensive denaturation of protein in cooking the crushed seed prior to oil removal. For feeding purposes this is generally considered desirable and appears to render the protein more readily assimilable by the animal. However, the damaging effect of heat on amino acids during processing has been noted in the processing of several oil seeds including soybeans (10), sunflowers (16), cottonseed (7), peanuts (3), mustard seed (14) and rapeseed (6). The basic amino acids, lysine, arginine and histidine, as well as cystine and tryptophan have been reported to be affected. Of these lysine appears to be the most heat sensitive. Conkerton et al. (7) studying cottonseed meal found that autoclaving meal for 2 hours reduced the lysine content by 37%, arginine by 15% and histidine by 13 percent. Cystine was also reduced by 19 percent. The amino acids were determined by acid hydrolysis and ion exchange analysis. Renner et al. (16) reported that autoclaving a commercial sample of sunflower seed meal for 4 hours at 15 lb (6.8 kg) steam pressure resulted in a decrease of 40% in lysine, 27% in arginine and 21% in tryptophan as determined after acid hydrolysis. They also reported that an increase from 93 to 116 C (200 to 240 F) in the cooker temperature and from 104 to 127 C (220 to 260 F) in the conditioner during commercial processing of sunflower seed resulted in a decrease of 15% in the lysine content of the meal. Similarly McGhee et al. (14) on prolonged heating of mustard seed meal found lysine was reduced by 64%, arginine by 30% and histidine by 15 percent. Reduction in lysine content has therefore been used as a measure of heat damage in the following discussion.

Two types of heat damage appear to take place. In one the amino acids are bound in such a form that they are not liberated by digestion *in vivo* or by enzyme hydrolysis *in vitro,* but are liberated by acid hydrolysis. In the second case the amino acids appeared to be irreversibly lost and are not recovered on acid hydrolysis. This was illustrated by Evans and Butts (10) for soybean meal. A commercial solvent-extracted meal was autoclaved for 4 hours and the lysine content determined before and after autoclaving using both acid and enzymatic hydrolysis. Acid hydrolysis showed a loss of 43% of the lysine and enzyme hydrolysis a loss of 61 percent. The effect of moisture during heating was also illustrated by the above authors. Dry

heat in an oven at the same temperature, 121 C (250 F), and for the same time as autoclaving resulted in no loss in lysine content either on enzyme or on acid hydrolysis.

The role of sugars in the irreversible loss of lysine was also pointed out by Evans and Butts (10). On autoclaving "alpha" protein from soybean meal there was virtually no loss of lysine, as determined after acid hydrolysis, whereas autoclaving the protein plus sucrose resulted in a 47% loss of lysine. This finding was substantiated by McGhee et al. (14) who found a direct correlation between the reducing sugar content and lysine content in mustard seed meal heated under varying conditions. Rapeseed, like mustard seed, contains thioglucosides which on enzymatic hydrolysis release glucose. It may be that in oil seeds of this type the "browning reaction" between sugars and amino acids presents a greater problem than in the processing of thioglucoside-free seeds.

The various processing steps in which protein damage can occur are in the cooker and the expeller in expeller processing; in the cooker, expeller and desolventizer in prepress plus solvent extraction; and in the cooker and desolventizer in straight solvent extraction. As can be seen from the foregoing discussion the extent of damage in these operations will depend on time, temperature, moisture content, reducing sugar content and possibly on the content of other constituents in the seed. Very little information is available on the extent of damage during these various operations in actual commercial operation. Bensabot and Frampton (3), in studying expeller processing of peanuts, found the lysine content was reduced 6% on cooking for 1 hour at 112 C (234 F) and dropped another 9% in the expeller which was operated at 149 C (300 F). On cooking for 2 hours at 120 C (248 F) the lysine content dropped 17% and was reduced by a further 17% in the expeller which was again at 149 C (300 F). Clandinin and Tajcnar (6) determined the lysine content on rapeseed meals from a commercial expeller plant in which the cooking temperatures had been recorded. The crushed seed was cooked for 30 min at temperatures ranging from 98 to 117 C (208 to 243 F) and conditioned for an additional 5 min at temperatures from 121 to 140 C (250 to 284 F). The lysine content of the meals varied from 3.69 to 5.37% of the protein, and was found to correlate with the fat content of the final meal which varied from 5.2% to 9.7 percent. Expeller pressing of rapeseed to obtain a meal with less than 6% residual fat resulted in a marked reduction in the lysine content of the meal. The average lysine content of the meals containing over 6% residual fat was 4.8% of the protein. Clandinin and Bayly (5) determined the essential amino acids in a number of varieties of rapeseed using the same method of analysis as was used for the above meals. In this case the oil had been extracted with a petroleum solvent and the resulting meal had not been heated. The average lysine content found for the six varieties tested was 5.3 percent. It therefore appears that in expeller processing some protein damage occurs even when 6% or more oil is left in the meal.

Clandinin (4) has also determined the amino acid composition of 15 samples of rapeseed meal from prepress plus solvent plants. The average lysine content of these meals was 5.5%, indicating little loss of lysine in this process. The crushed seed is cooked in this process and also is further heated in the desolventizer. The damage to protein in the straight expeller process, therefore, appears to take place in the expeller press itself but does not occur in the very mild pressing conditions used in the prepress plus solvent process.

Finlayson (11) found the lysine content of rapeseed meal from a straight solvent extraction plant to be 6.6% of the protein. This high value probably does not reflect a difference between this meal and prepress plus solvent meal but rather a difference in the method of hydrolysis and analysis of the amino acids. It should also be noted that all the values reported for rapeseed meal have been obtained after acid hydrolysis of the meal.

Effect of Processing on Thioglucosides

The thioglucosides in rapeseed, though only present in small amounts, are important because of their possible link with various deleterious effects observed when the meal is fed to animals. The amounts of these materials in the various varieties, their structures and their physiological effects will be dealt with in the following chapters. The discussion here will be limited to alterations in the thioglucosides which may take place during processing.

In general the thioglucoside content may be altered in two ways; first, by action of enzymes present in the seed and secondly, by chemical modification on heating in the presence of moisture and the other constituents of the seed. The effect of enzyme action in the case of oriental mustard seed (*Brassica juncea*) is well illustrated by the work of Goering (12, 13) and Mustakas (15). Mustakas investigated the effect of moisture, temperature and time on the enzymatic hydrolysis of the thioglucoside in the crushed mustard seed. Hydrolysis proceeded rapidly above moisture contents of 13% and at temperatures of 40 to 70 C (104 to 158 F). At a moisture level of 15.5% and temperature of 55 C (131 F) hydrolysis was 99% complete in 15 min and was over 90% complete in 1 minute. The hydrolysis products of the thioglucoside in oriental mustard are glucose, potassium bisulfate and allyl isothiocyanate (9). The latter compound is steam volatile so that the thioglucoside from mustard seed may be effectively removed by allowing enzymatic hydrolysis to proceed and then stripping out the isothiocyanate by steaming. In the process proposed by Mustakas (15) this is done prior to the oil extraction and that proposed by Goering (12) after oil extraction.

On enzymatic hydrolysis, the thioglucosides in rapeseed give rise to a cyclic, non-steam volatile oxazolidinethione as well as to volatile isothiocyanates. If enzyme hydrolysis were allowed to proceed in this case only

a portion of the organic sulfur containing products could be removed by steaming. If hydrolysis proceeds before oil extraction, a portion of the organic sulfur compounds enters the oil and subsequently poisons the nickel catalyst used in hardening the oil for use in margarines and shortenings. Reynolds and Youngs (17) have demonstrated the effect of cooking conditions on the ease with which rapeseed oil may be hydrogenated or hardened. Addition of water during cooking reduced the ease of hydrogenation of the resulting oil. That this was linked with the thioglucosides in the seed was substantiated by determination of these components in the resulting meals. If no water was added during cooking, virtually all of the isothiocyanates and oxazolidinethione in the seed could be accounted for in the meal, whereas cooking with the addition of moisture resulted in a substantial drop in the amount of these compounds in the meal. Since in Canada a large portion of the rapeseed oil produced is used in margarines and shortenings the present method of processing involves cooking the crushed seed without the addition of water and heating the seed to 80 or 90 C (176 to 194 F) as rapidly as possible to inactivate the enzyme before appreciable hydrolysis can occur. Under these conditions the thioglucosides are left in the meal.

Reynolds and Youngs (17) also found that at cooking temperatures above 110 C (230 F) the extracted oil did not hydrogenate satisfactorily regardless of whether or not water was added. This cannot be attributed to enzyme hydrolysis but may be a result of chemical breakdown of the thioglucosides to give oil soluble sulfur-containing compounds.

In the earlier expeller meals where water was added during cooking and relatively high temperatures were reached in the expeller some hydrolysis and possibly chemical degradation of the thioglucosides would be expected. This is indicated by the results of Clandinin (4) who found the average content of isothiocyanates and oxazolidinethione for five samples of expeller rapeseed meal to be 2.44 and 2.40 g/kg respectively. For 15 samples of prepress plus solvent meals these values were 4.18 and 3.58 g/kg. It must be stressed that these results can only be considered as an indication of the effect of processing because of the variation in thioglucoside content of rapeseed with variety and with growing conditions.

Belzile et al. (1, 2) have conducted a number of laboratory studies on various treatments of rapeseed meal following oil extraction in attempts to modify the thioglucoside content. These treatments included hot water extraction, dry heat, autoclaving, steam stripping and extraction with buffer solutions at various pH values. The conditions used in these treatments and the results obtained are given in Chapter 4. Although a number of these procedures gave a substantial reduction in the thioglucoside content or in the effect of these thioglucosides when fed to animals, none of the procedures are readily adaptable to commercial processing.

Summary

Although information on the effect of commercial processing on the quality of rapeseed meal is very meager some conclusions may be drawn. Expeller pressing results in protein damage as measured by the decrease in lysine content of the meal. The extent of damage, which appears to take place predominately in the expeller rather than in the cooking operation, increases as the residual oil in the meal is decreased by more rigorous processing conditions. Prepress plus solvent or straight solvent extraction has very little effect on the lysine content of the meal as determined after acid hydrolysis. No information has been obtained, however, on the content of available lysine before and after processing.

With respect to the thioglucoside content, the main alteration during processing is through enzymatic hydrolysis. This hydrolysis can proceed rapidly under suitable conditions of moisture and temperature. In current processing of rapeseed no water is added during cooking and the temperature of the crushed seed is raised as rapidly as possible to inactivate the enzyme and keep hydrolysis to a minimum. Under these conditions the bulk of the thioglucosides are left in the meal.

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CHAPTER 3. THE CHEMICAL COMPOSITION OF RAPESEED MEAL

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Introduction

Rapeseed is a member of the Cruciferae family which includes a number of other economically important plants, e.g., cabbage, cauliflower, turnip, mustard. There are several different types of rapeseed as discussed in Chapter 1. Two species are grown in western Canada: summer rape, *Brassica napus* var. *oleifera* f. *annua,* and summer turnip rape, *Brassica campestris* var. *oleifera* f. *annua*; these are frequently referred to as Argentine and Polish types respectively in Canadian literature. All references to rapeseed meals in this discussion will refer to the summer type unless otherwise designated. This chapter will deal only with those chemical components of the seed that are important in animal nutrition.

The two economically important products of rapeseed are the oil and the meal. The oil which is the primary product (38 to 44% of the seed) is used in the edible oil trade. Detailed fatty acid analyses of the oil have been made and these indicate that a high erucic acid content is typical of rapeseed oil (16, 17 and Chapter 1). The meal, which is the residue remaining after the oil has been removed, consists primarily of protein and carbohydrate. A little less than half of the rapeseed meal is composed of protein (N×6.25). Matét, Montagne and Buchy (34) reported that the carbohydrate content of European rapeseed cake varies from 20 to 25% while the cellulose content is 8 percent. These values are similar to those reported for linseed cake while the carbohydrate value in rapeseed is slightly higher than for sunflower cake. In another more detailed investigation Mizuno (36) reported that de-fatted *Brassica napus* contained the following simple carbohydrates: fructose (0.51%), glucose (0.21%), sucrose (1.11%), raffinose (0.15%) and stachyose (0.19%). The same investigator also reported the presence of a number of polysaccharides, which contained arabinose, galactose, ribose, galacturonic acid, glucose, xylose and rhamnose.

The proximate analyses of several rapeseed meals along with some other oil seed meals and feeds are tabulated in Table 3.1. The protein content of rapeseed meal is comparable with other plant meals, although lower than those from animal sources. The crude fiber content is higher than for other meals. The ash and nitrogen-free extract are similar for all the oil seed meals. A recent report by Moldenhawer (37) gives the

Table 3.1. Proximate composition (%) of rapeseed meal and other feedstuffs

Feedstuff	Dry matter	Protein	Fat	Crude fiber	N-free extract	Ash	Ca	P	Reference
Rapeseed meal									
Expeller									
B. campestris	94.0	35.2	7.0	15.5	29.5	6.8	0.71*	1.00*	4, 32
B. napus	93.2	43.9	6.4	13.7	23.3	5.9	0.57*	1.07*	4, 32
Solvent									
B. campestris	92.0	40.5	1.1	9.3	33.9	7.2	0.66*	0.93*	4
Soybean meal									
Solvent	89.3	45.8	0.9	5.8	31.0	5.8	0.32	0.67	15
Linseed meal									
Solvent	90.9	35.1	1.9	8.9	39.4	5.8	0.40	0.83	15
Sunflower meal									
Solvent	93.0	46.8	2.9	10.8	24.8	7.7	0.43	1.04	15
Fishmeal, herring	92.3	70.6	7.5	0.4	3.0	10.8	2.94	2.20	15
Meat meal	93.5	53.4	9.9	2.4	2.6	25.2	7.94	4.03	15
Oats	89.1	13.3	5.1	12.0	65.5	4.1	0.11	0.39	14
Barley	90.3	12.6	3.0	8.2	62.9	3.6	0.09	0.47	14
Wheat	89.1	14.3	1.9	2.9	78.9	2.0	0.06	0.41	14

*Values from Clandinin (10).

proximate chemical analyses for a number of rapeseed meals from three sources and found them to be similar to those reported in Table 3.1. This worker reported the protein, fat, fiber and ash of Polish, Swedish and French meals to be 33.9, 31.2, 36.5; 10.4, 8.5, 4.7; 13.8, 12.2, 12.5; and 8.3, 7.1, 5.5% respectively.

Protein and Amino Acid Content of Rapeseed Meal

The protein content has been determined on a large number of rapeseed samples and some variations have been observed depending on the species and the environmental conditions under which it was grown. Frequently it is difficult to compare samples because it is not known whether the meals are laboratory preparations or commercial preparations. One source of material in western Canada is the Co-operative Test which gives one an opportunity to compare various species of rapeseed grown in different areas. Downey (20) has assayed a large number of these for both nitrogen and oil content. For the years 1962 and 1963 respectively, de-fatted ground seeds of *Brassica napus* gave mean values of 47.1 and 48.0% protein (N $\times$ 6.25) while the mean values for *Brassica campestris* were 43.3 and 45.8% protein. The protein content of meals are generally higher in the brown soil zones of western Canada than in the black soil zones. This difference may be related to the fact that in general black soil zones receive a higher rainfall than the brown. Clandinin and Bayly (11) conducted a similar study on material grown in 1955 and found that there were significant differences in varieties, *B. napus* being higher in protein content than *B. campestris*; however, they found no significant difference between stations.

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One might expect considerable change in the biological or nutritional value of rapeseed protein following processing which would not necessarily be reflected in a chemical analysis. Clandinin, Renner and Robblee (12) reported that the protein analyses of two expeller-processed commercial meals were 43.3% for *B. napus* and 33.9% for *B. campestris*. In the same paper (*see* Table 3.5 (12)) values are given for seed processed at different temperatures and it would appear that the temperatures employed in this process had no profound effect on the protein content. Several Swedish workers have reported crude protein values for a number (species unknown) of processed rapeseed meals and these values generally agree with other reports. Bünger et al. (7) report a crude protein value for rapeseed meal which varies from 32.8 to 40.9 percent. In another investigation Jarl (28) reported that rapeseed cakes had a crude protein content varying from 38.0 to 39.6 percent. These same workers (7, 28) indicated that the true protein value is about 10% lower than the crude protein value. Slightly lower values of 30 to 35% were reported by Matét et al. (34) for commercial rapeseed cake.

In recent years there has been a modification in the processing of rapeseed in western Canada which has resulted in a better quality meal. The earlier meals were obtained exclusively from expeller-processed seed while the present meals are obtained from processes which employ a combination of expeller and solvent extraction or solvent extraction alone. These various processes are discussed in Chapter 2. Manns and Bowland (33) reported that the protein content of two solvent-processed meals of *B. campestris* were 36.7 and 37.9 percent. Comparison of the two *B. campestris* meals shown in Table 3.1 sugest that processing may have some effect on protein content; however, this difference is undoubtedly related to the difference in oil content of the meals; i.e., the solvent-extracted meal will have a higher protein content (N $\times$ 6.25) than the expeller meal simply because the former has less oil in it.

Advances in amino acid methodology in recent years have resulted in complete analyses of many feedstuffs. One of the first amino acid assays of rapeseed was published in 1946 by Roche and Michel (40). Their values, although limited, in general agree fairly well with present-day values. Table 3.2 summarizes the amino acid analyses for some selected rapeseed meals and compares them with other feedstuffs. The first three columns compare values for rapeseed meals collected from Canada (10), Belgium (19) and Sweden (1). The Canadian values are averages of a number of different commercial meals from prepress solvent or solvent extraction processes. The Swedish meal was obtained from *Brassica napus* (probably a winter type) while the Canadian meals were mixtures of *B. napus* and *B. campestris* (summer types). The origin of the Belgian meal is not known. There are some differences in the amino acid composition of these rapeseed meals with the greatest variation appearing in lysine, histidine, tryptophan and serine content. Rapeseed meal compares quite favourably with other

vegetable protein concentrates. One should point out that variations in amino acid composition may not reflect differences in the original material but rather differences in the processing methods employed.

Several workers have indicated that rapeseed is an inferior meal because of its low lysine content (*see* Table 3.2). Clandinin et al. (12) noticed that meals processed at high temperatures were nutritionally inferior and low in lysine. Clandinin and Tajcnar (13) reported that there was a correlation between lysine in the meal and the temperature at which it was processed. They determined the lysine content of a number of expeller-processed rapeseed meals for which the processing temperatures were recorded. They observed that a decrease in the temperature of the cooker and conditioner resulted in an increase in lysine content in the meal. They also found that there was a direct relationship between the oil content of the meal and the lysine content. This was believed to be directly associated with the fact that lower oil content in the meal indicated higher temperatures in the expellers. From their data they (13) recommended that the oil content of expeller-processed rapeseed meal should not be below 6% in order to avoid damage to the lysine present in the meal.

Table 3.2. The amino acid content of various rapeseed meals and other protein supplements (g of amino acid per 16.0 g of nitrogen)

Protein supplement	Rapeseed			Soybean	Sunflower	Fishmeal	Tankage
	Canadian	Belgium	Swedish				
Reference	(10)	(19)	(1)	(19)	(19)	(46)	(6)
Number of samples	15*	Unknown	1	Unknown	Unknown	Unknown	Unknown
Amino acids							
Arginine	5.5	7.7	5.6	8.3	9.1	5.9	5.8
Histidine	2.7	4.1	2.6	3.3	2.8	2.4	2.7
Lysine	5.3	6.8	3.5	6.5	3.5	5.7	6.0
Tyrosine	2.1	3.5	2.3	3.8	2.9	2.8	2.7
Tryptophan	1.2	2.3	2.0	1.5	1.4	1.2	0.7
Phenylalanine	3.8	4.9	4.0	4.8	5.1	4.8	5.0
Cystine	—	2.6	1.7	1.7	1.8	1.0	0.9
Methionine	1.9	2.3	1.1	1.8	2.2	3.0	2.0
Threonine	4.2	4.5	3.8	3.7	3.4	5.0	3.5
Leucine	6.7	7.6	5.7	8.1	6.9	10.0	8.6
Isoleucine	3.6	4.2	3.7	5.0	4.2	4.0	3.4
Valine	4.8	5.9	5.7	5.1	5.8	4.0	5.5
Glycine	4.8	5.2	6.3	4.4	5.6	—	—
Alanine	4.3	4.9	1.9	4.5	5.1	—	—
Serine	4.2	5.3	8.6	5.8	4.6	—	3.3
Aspartic acid	6.7	8.1	9.7	10.8	9.1	—	—
Glutamic acid	16.8	17.4	17.1	18.0	18.8	—	9.4
Proline	6.1	7.5	8.0	5.0	4.5	—	—
Crude protein (%)	37.4	36.2	57.0†	47.3	40.3	—	—

*Prepress-solvent and solvent-processed meals collected during 1958-61 and analyzed for amino acid content using a Beckman/Spinco Amino Acid Analyzer.

†Percentage based on an ash and moisture-free meal.

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Modern methods of processing rapeseed have resulted in meals that have a higher lysine content than meals processed a number of years ago. The use of solvents to extract the oil from the seed or a combination of expeller and solvent extraction allows the meals to be processed at much lower temperatures. Investigations on the amino acid content of these solvent-processed meals indicated that the lysine content is higher than that of former meals. Table 3.3 summarizes the data collected by Clandinin (10). The origin of the seed utilized for the preparation of the three meals is unknown. It is interesting to note that the amino acid composition is similar for most of the acids suggesting that the method of processing does not effect them. However, this is not the case for the basic amino acids and particularly for lysine, the content of which is from 20 to 30% higher for solvent-processed meals than for expeller-processed meals. It should be pointed out that about the same increase is observed for tryptophan. Also there seems to be some increase in the histidine and arginine content. Gray, Hill and Branion (25) showed the same general trend when they compared the amino acid composition of a commercial rapeseed meal with one that was prepared in the laboratory. The laboratory meal was prepared by extracting the seed with diethyl ether and the lysine content was much higher in it than in the commercial meal. These workers also found that

Table 3.3. The amino acid composition of expeller and solvent-processed meals (g of amino acid per 16.0 g of nitrogen)

Amino acid	Expeller*	Solvent†	Solvent‡
Arginine	5.09	5.47	5.52
Histidine	2.40	2.61	2.76
Lysine	4.39	5.17	5.60
Tyrosine	2.16	2.06	2.18
Tryptophan	0.94	1.17	1.28
Phenylalanine	3.74	3.70	3.94
Methionine	1.88	1.90	1.95
Threonine	4.08	4.11	4.36
Leucine	6.45	6.58	6.87
Isoleucine	3.71	3.59	3.70
Valine	4.76	4.79	4.89
Glycine	4.68	4.68	4.97
Alanine	4.21	4.22	4.43
Serine	4.03	4.11	4.35
Aspartic acid	6.58	6.61	6.94
Glutamic acid	16.16	16.51	17.50
Proline	5.71	5.94	6.50

Source of material
*Saskatoon, Saskatchewan (5 different meals).
†Altona, Manitoba (10 different meals).
‡Lethbridge, Alberta (5 different meals).

the tryptophan and tyrosine content was lower in the commercial meal. It was again suggested that one of the factors affecting the amino acid composition of the meal was the processing temperature.

Some work has been done on the amino acid content of different varieties of rapeseed. One of the more comprehensive studies has been made by Clandinin and Bayly (11), in which they determined and compared nine amino acids in both *B. napus* and *B. campestris*. Only lysine and histidine showed any significant differences, lysine being significantly higher in *B. campestris* while histidine was higher in one variety of *B. napus*. The same workers also investigated the effect of environmental conditions on the amino acid composition of rapeseed meal and again found that the greatest effect was exerted on the lysine content. Recently, Miller et al. (35) in a detailed study of the amino acid composition of the seed meals of 41 Cruciferae species compared *B. napus* and *B. campestris* and found very little difference in the amino acid content. They also found no difference between seeds of the same variety grown in Sweden and in Canada.

Amino acid analyses performed on commercial meals derived from different varieties indicate that there are a few differences. As indicated above there are very few differences between expeller and solvent-processed meals except in the lysine content (10, 32). However, a recent report by Finlayson (23) would indicate that perhaps the amino acid composition of rapeseed meal should be reinvestigated. Table 3.4 shows that the amino acid content of a solvent-processed *B. campestris* (Arlo variety) is markedly different than that reported by Clandinin (10) also for a *B. campestris* (variety unknown). The following amino acids are considerably higher in the report by Finlayson: lysine, tyrosine, phenylalanine, threonine, leucine, valine, glycine, aspartic acid and glutamic acid. One is not able to determine whether this is a varietal difference or whether it is a difference in the assay technique. Recently an interesting paper by Tristram and Smith (45) points out that great care must be taken in the determination of amino acids, particularly when one is preparing the hydrolyzate. An illustration of this point relates to the liberation and loss of certain amino acids, e.g., considerable quantities of serine and threonine are lost after 20 hours of hydrolysis while valine and isoleucine are completely released after 60 hours' hydrolysis. It would appear that it is extremely important to be aware of these difficulties when one compares various amino acid assays on feedstuffs.

Fat Content of Rapeseed Meal

In this chapter fats are considered to be the same as ether extract values found in various tables of feed analyses, although it is recognized that ether extracts contain materials other than fats. The fat content of the meal will depend on the processing method employed. The earlier meals which were mainly processed by employing Anderson expellers had fat contents which varied from 6 to 7 percent (10, 32, 44). Meals obtained from

Table 3.4. The amino acid composition of commercial solvent-processed *B. campestris* (g amino acid per 16.0 g of nitrogen)

Amino acid	Meal 1 (10)	Meal 2 (23)
Arginine	4.9	4.0
Histidine	2.4	2.5
Lysine	5.0	6.6
Tyrosine	1.9	3.2
Tryptophan	1.2	—
Phenylalanine	3.5	4.7
Cystine	—	1.3
Methionine	2.0	1.4
Threonine	4.2	5.3
Leucine	6.4	8.7
Isoleucine	3.5	4.4
Valine	4.7	5.7
Glycine	4.7	5.6
Alanine	4.1	5.1
Serine	4.1	5.3
Aspartic acid	6.6	8.1
Glutamic acid	16.2	24.6
Proline	6.2	8.0

solvent-processed seeds have a much lower fat content, varying from below 1 to 2 percent. There are no reports on the composition of the fat but undoubtedly it consists primarily of the oil found in the original seed and therefore the fatty acid composition of it would be similar to the oil. It is known that environmental conditions such as rainfall, soil type and fertilizer practices have an effect on the oil content and fatty acid composition of oil seeds (41).

Crude Fiber Content of Rapeseed Meal

Crude fiber in animal feeds refers to lignin and insoluble carbohydrate material, e.g., cellulose. Reference to Table 3.1 on proximate composition of feedstuffs shows that rapeseed meal has a higher fiber content than other oil meals. The value ranges from 9 to 16% and the fiber content does not differ when solvent and expeller–processed meals are compared (10, 28, 32, 44). Rapeseed meal has a higher fiber content than soybean meal but it is only slightly higher than sunflower or linseed meal.

Mineral Content of Rapeseed Meal

The ash content, which indirectly is a measure of the mineral content, of rapeseed meal varies depending on the source of the seed. The ash for meals obtained in western Canada vary from 6 to 7 percent (10, 32). Those grown in Sweden are higher (44); a value of approximately 8% is indicated. The calcium and phosphorus content of Canadian meal is 0.60 and 1.10% respectively as reported by Clandinin (10); slightly higher values are reported for Swedish meals (44). In general the calcium and phosphorus content of rapeseed meal is similar to that of other oil seed meals (*see* Table 3.1). Sawhney and Kehar (42) reporting on the manganese content in animal feeds obtained a value of 153.5 ppm for rapeseed cake. The range for nine other vegetable seed meals was 39.5 to 80.0 ppm, thus indicating that rapeseed is a rich source of this mineral.

Vitamin Content of Rapeseed Meal

Very little information of the vitamin content of rapeseed meal is available. One of the more detailed investigations of the vitamin content has been reported by Klain et al. (32) and their results are presented in Table 3.5 along with three other meals (15). Their (32) results suggest that there is no significant difference in the vitamin content of two varieties of rapeseed analyzed. When compared with other vegetable seed meals it is seen that the choline content of rapeseed meal is higher. The niacin content of rapeseed is higher than for soybean or linseed but lower than for sunflower meal. The thiamine and pantothenic acid content of rapeseed meal is much lower than for the other three meals. An Indian report (24) on *B. campestris* indicates a much lower value for free niacin, 42 mg per kg, than that reported in Table 3.5. However, it is impossible to compare these values as they were carried out on samples collected in widely separated areas.

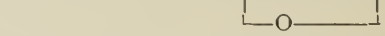
Table 3.5. The vitamin contents (mg per kg) of expeller-processed rapeseed meal and other oil seed meals

Vitamin	Rapeseed (32)		Soybean (15)	Linseed (15)	Sunflower (15)
	Brassica napus	*Brassica campestris*			
Thiamine	1.9	1.7	6.6	9.5	34.5
Riboflavin	4.2	3.3	3.3	2.9	3.3
Pantothenic acid	9.9	8.6	14.5	17.8	41.0
Niacin	167.0	152.0	26.8	30.1	291.0
Choline	7,000	6,450	2,740	1,230	4,300

Isothiocyanate and Oxazolidinehione Content of Rapeseed Meal

These compounds are present in rapeseed meal in only small amounts but they may exert a considerable effect on the nutritional value of the meal. Early reports (5, 8, 27) demonstrated that rapeseed meals caused a depression in growth and in many cases an enlargement of the thyroid when fed to animals or fowl. (-)-5-Vinyl-2-oxazolidinethione (also referred to as (1)-5-vinyl-2-thioxazolidone, however this is no longer the accepted name) which exists in rapeseed was shown to be closely associated with the enlargement of the thyroid (3). The thioglucosides from which these sulfur-containing compounds are derived, their enzymatic breakdown, and their characterization in rapeseed are discussed in Chapter 4. The present chapter will be concerned only with the quantitative assay of these compounds and the basis for these determinations.

The quantitative assays as described by Wetter (47, 48) are based on the following properties: the major isothiocyanates in rapeseed meal are volatile and therefore are removed from the reaction mixture by steam distillation (47), the oxazolidinethione is not volatile and therefore stays behind in the reaction mixture (48). The volatile isothiocyanates in rapeseed consist of two major ones, 3-butenyl isothiocyanate ($CH_2{=}CHCH_2CH_2NCS$) and 4-pentenyl isothiocyanate ($CH_2{=}CHCH_2CH_2CH_2NCS$), and one minor one, 2-phenylethyl isothiocyanate (30). There are some differences in the proportions of the two major isothiocyanates; in *B. napus* the predominant one is 3-butenyl isothiocyanate (22, 31) while in *B. campestris* the two major isothiocyanates are present in approximately equal proportions (50). (-)-5-Vinyl-2-oxazolidinethione



is the primary non-volatile component and therefore remains in the reaction mixture from which it can be extracted and assayed as described by Wetter (48). This sulfur compound exerts a strong anti-thyroid effect and it was isolated and identified by Astwood et al. (3). The presence of oxazolidinethione in rapeseed meal was definitely established by Raciszewski et al. (39). The cyclic compound does not exist as such in the natural state but rather as the thioglucoside which on enzymatic hydrolysis yields 2-hydroxy-3-butenyl isothiocyanate ($CH_2{=}CH{-}CHOHCH_2NCS$) (26, 43). The latter compound is not stable and cyclizes to the (-)-(5-vinyl-2-oxazolidinethione (29). Therefore discussion of mustard oils in this section refers to the isothiocyanates which are the volatile sulfur compounds and the non-volatile portion which is primarily made up of the oxazolidinethione.

There is considerable information available on the mustard oil content of rapeseed, but most of it cannot be compared because of the variability of material from different sources. First, the mustard oil content of de-fatted seeds will be dealt with and later the effect of processing will be discussed. Wetter and Craig (49) in a study of seven different varieties found that the isothiocyanate content varied from 4.33 to 5.36 mg per g

of oil-free meal, while the oxazolidinethione varied from 1.33 to 5.60 mg per g of meal. Unpublished values obtained by Clandinin (10) showed a range of 2.10 to 3.08 and 1.04 to 3.35 mg per g for isothiocyanate and oxazolidinethione respectively in expeller meals and a range of 2.39 to 5.55 and 1.83 to 6.39 mg per g for the above mustard oils in prepress-solvent and solvent-processed rapeseed meals. Daxenbichler et al. (18) report the following values for a sample of *B. napus*; 5.9 to 6.0 and 4.3 to 6.2 mg per g for isothiocyanate and oxazolidinethione respectively. Appelqvist (2) reported on the isothiocyanate and oxazolidinethione content of various rapeseeds grown in Sweden and he obtained somewhat different values as shown in Table 3.6. In a study carried out on 124 samples of rapeseed, Nehring and Schramm (38) obtained an average isothiocyanate content of 2.6 mg per g of oil-free seed.

The mustard oil content for different species of rapeseed varies considerably as shown in Table 3.6. The major difference exists in the oxazolidinethione content; *B. campestris* has a significantly lower content than does

Table 3.6. Mustard oil content of different rapeseed species (all summer types)

Species	Isothiocyanate mg per g	Oxazolidinethione mg per g	Reference
B. campestris	4.80	1.56	(49)
*B. campestris**	4.35	2.15	(10)
B. campestris†	7.20	0.90	(2)
B. napus	4.59	5.44	(49)
*B. napus**	3.12	5.34	(10)
B. napus†	3.00	3.00	(2)

*Solvent-processed commercial meals.
†Summer types grown in Sweden.

B. napus. The same observation was made for winter types grown in Sweden (2). Both Wetter (49) and Clandinin (12) found that *B. campestris* had a lower oxazolidinethione content than did *B. napus*. There appear to be some differences in the isothiocyanate content but it is not of the same magnitude as was observed for oxazolidinethione. Wetter (49) reports that there is a significant difference in some of the varieties grown in western Canada.

Only scattered results are available on the effect of environment on the mustard oil content of rapeseed. Studies in other areas have shown that environmental factors have an effect on the oil content and fatty acid composition of oil seeds (41). Clandinin et al. (12) in their study indicate that the environmental conditions under which the seed is grown

affect the oxazolidinethione content. Wetter and Craig (49) made the same observations in a study that included six regions in western Canada. Neither study was extensive enough to assess whether the differences were due to variations in rainfall, soil type, length of day or other causes. There was no significant difference in the isothiocyanate content reported by either group of workers. That environmental conditions may have an effect on the mustard oil content of rapeseed is shown in a fertilizer study recently undertaken by Downey and Wetter (21). These investigators added sulfate fertilizers to plots of rapeseed grown on grey wooded soil. It was found that the response to sulfur fertilizers was much greater for *B. napus* than for *B. campestris*. The increase associated with fertilization was about two times for the oxazolidinethione and about four times for isothiocyanate.

The effect of processing on the mustard oil content of rapeseed meal has not been extensively studied. Raciszewski et al. (39) reported oxazolidinethione values ranging from 2.4 to 4.2 mg per g for three commercial samples. Since these meals likely were a mixture of different species, one would have no way of comparing them with the original seed. In a study conducted on processed and nonprocessed meals Clandinin et al. (12) conclude that high temperatures during the processing step increase the oxazolidinethione content of rapeseed meal, whereas in another report Clandinin (9) shows that excessively high temperatures lower the oxazolidinethione content of the meal. Processing procedures have a marked effect on the isothiocyanate content of rapeseed. If the seed is moist and allowed to stand for a period of time and is then heated or treated with steam the isothiocyanate content will be much lower than in the original seed. In fact this is a method employed in processing the meal to reduce the isothiocyanate content of meal. These aspects will not be discussed here as they are dealt with in Chapter 2.

Summary

The chemical composition of rapeseed meal has been discussed. Much of the information gathered pertains to two areas; the amino acid composition and the mustard oil content of rapeseed meal. The amino acid composition of the meal is comparable to other vegetable protein meals. Although there is some variation in the amino acid composition, it is not possible at the present time to ascertain what is causing these differences. There are definite varietal differences in the mustard oil content and composition of rapeseed meal. Here also there are variations that cannot be accounted for but undoubtedly are related to such environmental factors as rainfall, soil type and soil nutrients. The information on the vitamin and mineral content of the meal is limited, however it indicates that they are similar to other plant meals. It is hoped that more information regarding the mineral and vitamin content of rapeseed meal will be forthcoming in the future.

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CHAPTER 4. GOITROGENIC PROPERTIES

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Introduction

The use of rapeseed meal as a protein supplement in livestock and poultry rations has often resulted in adverse effects on growth and reproduction. There have been appreciable differences, however, according to animal species, age and sex, as well as method of processing of rapeseed for oil extraction and meal preparation; species or variety of rape; year the crop was grown and other factors.

The undesirable principles in rapeseed meal are derived mainly from the thioglucosides which yield isothiocyanates and oxazolidinethione upon enzymatic hydrolysis. These or related compounds are characteristic of many plants or their seeds, particularly in the Cruciferae, or mustard family, to which the genus *Brassica* belongs.

The "Mustard Oils"

The existence of the so-called "mustard oils" (isothiocyanates and oxazolidinethione) has been known for a long time. According to Challenger (19), early users of mustard probably knew that it was necessary to grind the seeds with water to produce the characteristic odor but this observation is historically attributed to Portas in 1608. The Dutch scientist Boerhaave in 1732 appears to have been the first to prepare oil of mustard and describe its properties. Dumas and Pelouze in 1833 undertook elementary analysis of mustard oils and showed that these could yield ammonia and thiourea. This work is generally regarded as the beginning of the modern investigations relating to mustard oil and its production from plants and seeds.

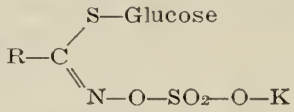
Reports published up to 1948 (66, 74) indicated that more than 30 isothiocyanates had been isolated from plant sources. However, many more compounds of this type have been found since then, such that the number now probably exceeds forty.

Allyl isothiocyanates (from sinigrin), p-hydroxybenzyl isothiocyanate (from sinalbin), sec.-butyl isothiocyanate and beta-phenylethyl isothiocyanate appear to have been the only mustard oils of known structure prior to 1952 (44). At that time a systematic investigation of the natural mustard oils and their thioglucosidic precursors was begun, principally by

Kjaer and his Danish colleagues. Much of this work, still in progress, has been concerned with plants and seeds belonging to the natural order Cruciferae but recently other orders have been studied (3, 34, 43, 45, 46, 48, 49, 65, 67).

The Thioglucosides

In 1840, Bussy (19) obtained a substance, sinigrin, by aqueous extraction of pre-heated black mustard seeds (*Brassica nigra* L.). When this compound was treated with "myrosin", previously isolated from the same seeds by Boutron and Fremy (19), oil of mustard (allyl isothiocyanate) was liberated. This clearly established the simultaneous presence of a thioglucoside and thioglucosidase in the same seed. Sinigrin was the first thioglucoside isolated from plant sources of the many now known. The general formula is:

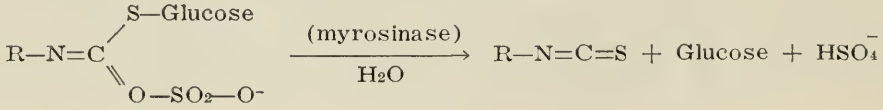


Sinablin has a more complex structure. Instead of yielding $KHSO_4$ upon hydrolysis it gives, in addition to glucose and p-hydroxybenzyl isothiocyanate, the hydrogen sulfate of an ester derivative of choline and sinapic acid, known as sinapin sulfate. Sinalbin is present in rapeseed (47) and Clandinin (22) and Schwarze (69) ascribed to it the cause of the bitter taste of the seed.

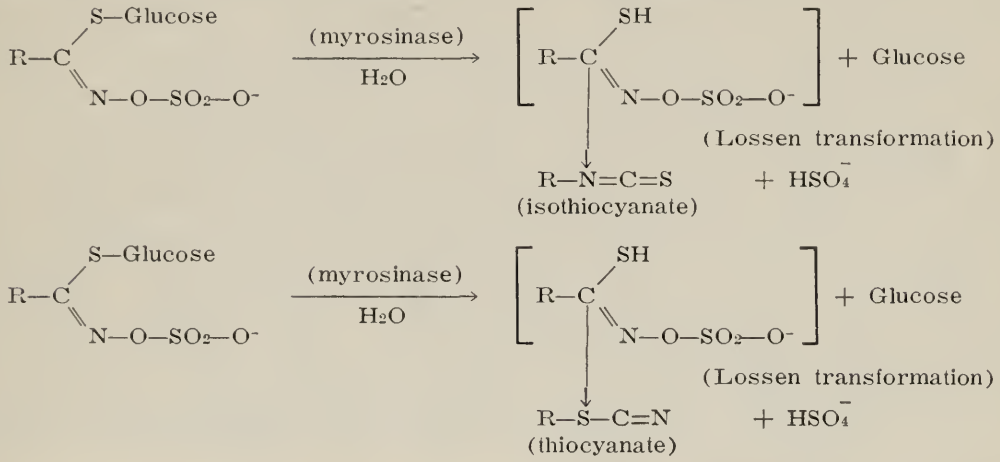
Myrosinase

The thioglucosidase, myrosinase, is the enzyme usually responsible for the hydrolysis of the mustard oil thioglucosides found in many representatives of the Cruciferae, Tropeolaceae, Capparidaceae and Rosedaceae. Boutron and Fremy (19) are credited with the first crude enzyme preparation in 1840 although they apparently did not realize that they had an enzyme. They extracted black mustard seeds with cold alcohol and obtained a solid substance subsequently named myrosin.

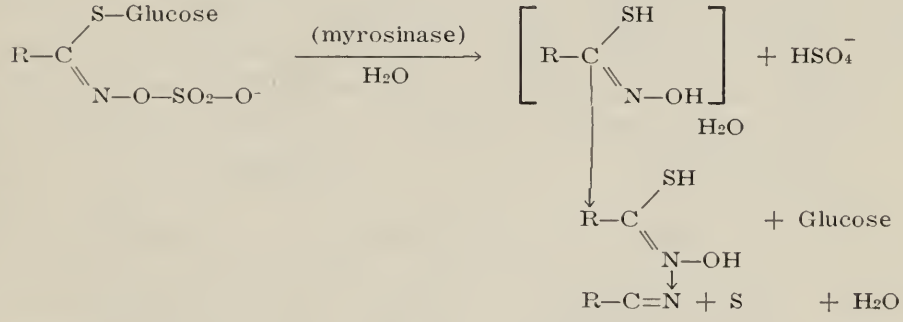
Myrosinase effects the cleavage of a thioglucoside to yield isothiocyanate, bisulfate and glucose. Two explanations have been proposed for the enzymatic breakdown. The earlier explanation proposed by Gadamer (29) suggested that the enzymatic decomposition involved a simple hydrolytic mechanism yielding only isothiocyanates; other compounds such as nitriles arising by a purely chemical reaction possibly catalyzed by the bisulfate ion. Such an explanation is due partly to an erroneous early concept of the structure of thioglucosides and partly to the absence of adequate information concerning the products of their breakdown. Gadamer's enzymatic mechanism is given below:



His formula for thioglucosides as well as his reaction mechanism remained unchallenged for 60 years. In 1956, Ettlinger and Lunden (28) proposed a revised structure for thioglucosides and a new mechanism of reaction (*see* formula on page 46). During the intervening period, various observations had emerged which suggested that not all of the decomposition products of thioglucosides could be readily explained by Gadamer's formula, especially the occasional simultaneous formation of nitriles and isothiocyanates or thiocyanates and mustard oils. This new structure permitted a second explanation of hydrolysis by myrosinase, more complex in nature but also more in line with the experimental facts. According to this view, the action of myrosinase can give rise to isothiocyanates, thiocyanates or nitriles but the prominent reaction involving a Lossen transformation yields isothiocyanates (in some cases thiocyanates):



In a reaction where nitrile formation occurs, the anion is preferentially eliminated:



The simultaneous occurrence of a nitrile and an isothiocyanate has been observed on several occasions. Will and Korner in 1863 (19) fractionated two samples of natural oil from the seeds of black mustard (*Brassica nigra* L.) and found allyl cyanide as well as allyl isothiocyanate. Schultz and Gmelin in 1954 (68) reported that when glucoiberin, a thioglucoside obtained from *Iberis amara* L. (rocket candituft), was treated with myrosinase-free sulfur, a nitrile and relatively little isothiocyanate

were produced. In 1948, Schmid and Karrer (66) isolated sulforaphene and the corresponding nitrile from radish seeds (*Raphanus sativus* L.) although enzymatic decomposition was not employed. The isolation of a nitrile and the corresponding isothiocyanate (4-pentenyl isothiocyanate) from rapeseed (*Brassica napus* L.) has also been reported by Schmalfuss (65), in 1936, using direct distillation procedures. Later Kjaer (48) treated crushed rapeseed with myrosinase and isolated by chromatography 4-pentenyl isothiocyanate as one of the products of the reaction but *not* the nitrile. Other cases of this kind are reported in the literature. These results indicate that, in certain circumstances, thioglucosidic breakdown can give rise to nitrile formation.

Recently Gmelin et al. at Helsinki (31) have found that the so-called garlic odors of some of the representatives of the Cruciferae family are due to the enzymatic decomposition of the thioglucosides to yield thiocyanates. This is true of the seeds of penny-cress (*Thlaspi arvense* L.) and two species of pepper-grass (*Lepidium ruderale* L. and *Lepidium activum* L.) which liberate allyl thiocyanate, benzyl thiocyanate and a mixture of benzyl thiocyanate and isothiocyanate respectively. Attempts by these workers to separate a thiocyanate-forming enzyme from these seeds were unsuccessful since such enzyme preparations, in *in vitro* experiments, have always split glucosides to isothiocyanate in the normal way. They have obtained evidence, however, suggesting that in some of these plants there is a certain factor which regulates the migration of the radical to the S-atom instead of the N-atom during the Lossen transformation and concluded that it is possible that the quantity of this factor determines the presence or absence of thiocyanate formation.

Since the discovery of myrosinase, controversy has existed as to whether myrosinase is a one- or a two-enzyme system. Early workers (64, 76) believed that it consisted of two entities: a thioglucosidase capable of splitting the glucose moiety and a sulfatase capable of removing sulfur. Their assumption was based partly on the fact that the amount of enzyme required to remove the optimal quantity of glucose was greater than the amount of enzyme required to split off the optimal amount of sulfur. In contrast, more recent work favors the theory of a one-enzyme system for myrosinase (28, 59). This was based on the inability by fractional precipitation, electrophoresis and other methods to separate two enzymes. However, more recently, Gaines and Goering (30) have obtained results showing conclusively the dual nature of myrosinase. A crude enzyme preparation from *Brassica juncea* L. (Indian mustard) was fractionated with ammonium sulfate and diethyl amino ethyl cellulose. A fraction with sulfatase and another with thioglucosidase were obtained. They also showed that total hydrolysis only occurred when the two components were present.

Myrosinase is probably an -SH dependent enzyme since it is inactivated by inhibitors of that chemical group (64); also it is activated *in vitro* by ascorbic acid (27).

Greer (35) has discussed the finding of enzymes in the gastrointestinal tract capable of hydrolyzing thioglucosides. Several bacterial species were found to possess appropriate enzymes, notably *E. coli* and *A. aerogenes*.

Chemical Nature of Thioglucosides in Rapeseed

Although the mustard oil of rapeseed had been repeatedly investigated, no clear picture of its chemical nature existed until Kjaer's investigations in 1952. In 1899, Jorgensen (41) attributed the toxicity of rapeseed cakes to a C_5 or C_6 isothiocyanate in addition to the allyl derivative. In 1901, Sjollema (70) reported the isolation of a mustard oil to which he ascribed the structure: $CH_2{=}CH{-}(CH_2)_2{-}NCS$. Stein (71) obtained from Indian rapeseed cakes (*Brassica juncea* L.) a C_5 compound which he regarded as $CH_3{-}CH{=}CH{-}CH_2{-}NCS$. In 1936, Schmalfuss (65) again reported the isolation of $CH_2{=}CH{-}(CH_2)_2{-}NCS$, also its corresponding nitrile and a higher boiling isothiocyanate of unknown structure. Andre and Delaveau (2) found evidence in rape for the presence of three individual volatile isothiocyanates but again no suggestion as to their chemical nature. That three volatile mustard oils are present in rapeseed was later confirmed by Kjaer (44, 48). He succeeded in isolating and conclusively identifying 3-butenyl and 4-pentenyl isothiocyanate. The third factor, a minor one, is probably 2-phenylethyl isothiocyanate. Astwood et al. in 1949 (3) isolated and characterized (-)-5-vinyl-2-oxazolidinethione from rapeseed.

Using paper chromatography, Kjaer (48) has found evidence for the presence of six thioglucosides in *Brassica napus* L.: three major and three minor ones. His results on aqueous extracts of the seeds are given in Table 4.1.

The same pattern has been obtained repeatedly for seed samples of different origin and is therefore regarded as characteristic of varieties of *Brassica napus* L. This description accounts for the isothiocyanates in

Table 4.1. Thioglucosides and mustard oils in *Brassica napus* L.

Order of appearance from origin	Thioglucoside		Mustard oil	
	Nature	Magnitude	Nature	Characteristic
1	Probably gluco-coiberin	Minor	3-Me sulfinyl propyl isothiocyanate	Nonvolatile
2	Progoitrin	Major	Goitrin	Nonvolatile
3	Sinalbin	Minor	p-OH benzyl isothiocyanate	Volatile
4	Gluconapin	Major	3-butenyl isothiocyanate	Volatile
5	Gluco-brassiconapin	Major	4-pentenyl isothiocyanate	Volatile
6	Probably gluco-nasturitium	Minor	2-phenyl ethyl isothiocyanate	Volatile

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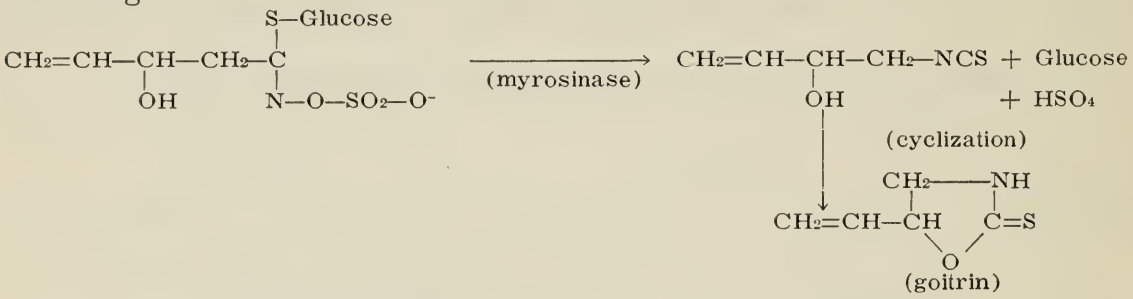
rapeseed, a subject of discussion in the literature through more than five decades, but no mention is made by Kjaer of the presence of sinigrin in rapeseed as reported by Matét (56).

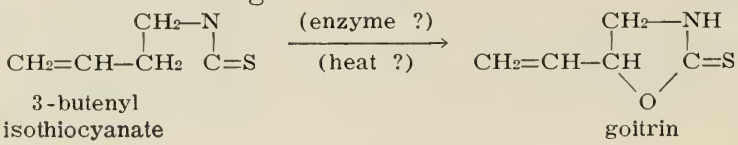
With minor variance, Gmelin et al. at Helsinki (31) have corroborated Kjaer's work. In some *Brassica* species, they have found five and in others only two thioglucosides. Both Kjaer and Gmelin agreed that progoitrin and gluconapin are the chief thioglucosides in rapeseed species.

Goitrin and its precursor progoitrin deserve special mention. In 1949, Astwood and Greer (3) isolated a compound from several kinds of *Brassica* seeds (including *Brassica napus* L.), which turned out to be (-)-5-vinyl-oxazolidinethione. This compound absorbs strongly at 240 millimicrons. It was found to be goitrogenic and to posses an activity equal to thiourical when injected into humans and 20% as active when injected into rats. It was given the descriptive name: goitrin. These workers found that goitrin was not formed when the enzymes were destroyed by suspending the seeds in boiling water but that subsequent treatment of the filtrate with myrosinase liberated it. Therefore goitrin exists in the seed as a glucoside and the latter was given the name: progoitrin. Recently Greer (34) isolated progoitrin and described its properties. This compound absorbs at 227 millimicrons. Other oxazolidinethiones are also known to exist in nature: L-5:5-dimethyl-2-oxazolidinethione and L-5-methyl, 5-ethyl-2-oxazolidinethione in the seeds of *Coringia orientalis* L. (hare's-ear mustard) and L-5-phenyl-2-oxazolidinethione in *Reseda lutea* L. (cut-leaved Mignonette) (19).

Evidence based on the ultraviolet shift experienced during enzymatic hydrolysis and on the infrared spectrum of progoitrin indicates that oxazolidinethione is not preformed in the thioglucoside molecule but arises from cyclization following enzyme action. The reaction is probably the following:



Pitt-Rivers (62) in 1950 postulated that 3-butenyl isothiocyanate may give rise to goitrin by cyclization, perhaps via an enzyme. Clandinin (25) has found that heat increases the goitrogenic properties of rapeseed meal by converting isothiocyanate to (-)-5-vinyl-2-oxazolidinethione. Perhaps the mechanism is the following:



Evidence for Goitrogenic Properties

The existence of an antithyroid substance has been known for many years but the first definite evidence of a goitrogen in food was discovered accidentally by Chesney et al. in 1928 (20). They found that a colony of rabbits on a maintenance diet of fresh cabbage, oats and hay developed truly remarkable goiters, in one case the thyroid reaching 43 g as against an average of 0.23 g for 644 normal rabbits. By the process of elimination, they concluded that cabbage was responsible for this phenomenon (21). Marine (54, 55), McCarrison (57, 58), Blum (16, 17) and others were able to reproduce this phenomenon of "cabbage goiter" although some investigators were less successful (35).

Earlier, Sjollema in 1901 (70) had identified crotonylisothiocyanate as a constituent of the essential oil fraction of rapeseed. Viehover et al. (75) in 1920 found crotonyl- and allyl-isothiocyanates present in rape and mustard seeds respectively, and established their relative toxicities with rabbits but did not associate the adverse effects with thyroid dysfunction.

Kennedy and Purves in 1941 (42) appear to have been the first to report goitrogenic properties attributable to components of rapeseed. Having found previously that drying could destroy the activity of cabbage, it was reasoned that the goitrogens might be glucosides (38). Therefore they turned to those seeds long known to be rich in glucosides: rape and mustard. These seeds produced enlarged thyroids (22 to 25 mg/100 g of body weight) when fed to rats for 30 days. The appropriate generic term "Brassica-seed goiter" was coined to describe this effect.

Extending these investigations they found that young rats would develop thyroids three- to four-fold larger than the controls even though the iodine intake was adequate (42). They also found that in rats the goitrogenic effect reached a plateau after feeding rapeseed for 3 weeks but the thyroid reaccumulated some colloid after 9 or more weeks on treatment. However, the hypertrophy of the gland was not alleviated. Recently similar results were obtained in rats and pigs (51, 52, 53).

It soon became apparent that all types of expeller-processed rapeseed meal produced goitrogenic effects of various intensity in non-ruminants. Pettit in 1944 (61) reported that 20% rapeseed meal in a chick starter caused thyroid hytertrophy. Turner in 1946 and 1948 (72, 73) reported that the feeding of various levels of rapeseed to chicks led to increased thyroid sizes. Recently Clandinin (24) reported that upon feeding expeller meal to chicks, the thyroid-to-body-weight ratio doubled when a 15% Polish (summer turnip rape) or 5% Argentine (summer rape) level was used, the difference between the two types of meal being due presumably to the variation in goitrogen content. Using turkey poults, Blakely and Anderson (13) observed a five- to six-fold increase of the thyroid weight as a result of feeding rations containing up to 20% rapeseed meal. In rats, the goitrogenic effect was evident when 10% Argentine meal was incorporated in a ration

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(40), and Manns et al. (53) have shown that although the serum PBI was not affected by rapeseed, the standard metabolic rate was lowered. Bell (6) observed some thyroid enlargement due to the feeding of Argentine meal to mice and it is known that metabolic rate is reduced upon prolonged feeding. The goitrogenic effect of rapeseed feeding to swine has been repeatedly demonstrated (40, 60) and Manns et al. (53) have shown that the PBI is reduced upon prolonged feeding.

There is no evidence indicating that rapeseed meal is goitrogenic to ruminants. Bezeau et al. found no thyroid enlargement in ewes fed as much as 30% rapeseed meal in their rations (12). Rapeseed meal has been used in cattle feeds in Europe for many years with no apparent ill effects.

Although the goitrogens of cabbage appear to be counteracted by sodium iodide either as fertilizer applied to the growing plant (18) or as a supplement in the animal diet (55), only partial correction, if any, has been obtained with iodide in diets containing rapeseed meal and involving several animal species (9, 50, 63). On the other hand, more success resulted from the use of iodinated casein or thyroxine. These substances counteracted to varying degrees the goitrogens of rapeseed when added to rat (63), turkey poult (14, 15) and chick (50) diets. Other species like the mouse and the pig have not responded satisfactorily to the feeding of thyroid hormones (7, 60).

It has been shown by Kennedy and Purves (42, 63) that hypophysectomy will prevent the development of thyroid hypertrophy. The hypophysectomized rats possessed glands weighing no more than 6.4 mg as compared to 44 mg for the intact controls. They also demonstrated that rats placed on the "active" diet for 2 months and then hypophysectomized showed colloid formation and a reduction of thyroid size. Thyroxine abolished thyroid hyperplasia induced by rapeseed feeding but iodide or diiodotyrosine did not to any significant extent, even when fed in large doses. These observations pointed to one conclusion: a rapeseed diet produces thyroid hypertrophy by interfering with the synthesis of thyroxine; this in turn stimulates the anterior pituitary to produce TSH which acts on the thyroid and causes hypertrophy and hyperplasia. With the feed-back mechanism for thyroid control interrupted, goitrogenesis continues. The observation by Kennedy in 1941 (42) and Manns et al. (53) in 1963 that an involution of goitrogenesis was evident after 2 months' feeding of rats is more difficult to explain on the basis of Kennedy's hypothesis.

A recent study of the thyroid glands of growing chickens and laying hens fed rapeseed meal with and without iodide supplementation was made by Clandinin (24). In growing chicks, the feeding of rapeseed was found to increase the thyroid size by a rise in the number of follicles and epithelial cells. When iodine was added to the rapeseed diet, the glandular enlargement was caused by increased follicular size and colloid storage. A somewhat similar histological picture held true for the laying hens. Such evidence

indicates that iodine supplementation, although mostly ineffective in counteracting goitrogenesis, may have a marked influence on the amount of colloid stored in the gland (25).

Mottled thymus, hypertrophied kidney and liver may follow the ingestion of rapeseed (5, 33). Manns et al. (53) found that adrenal and gonad weights, in rats and pigs, were unaffected by dietary rapeseed meal and that these glands also appeared normal histologically. Haas (37) detected a drop in the eosinophil count and a depletion in ascorbic acid content of the adrenals of rats following ingestion of mustard oils.

Greer et al. (36) have classified antithyroid compounds into seven categories according to their modes of action. Some obviously do not apply to the problem of toxicity in rapeseed meal, according to information presently available. Among those deserving comment, however, in this discussion is thiocyanate, the compound responsible for "cabbage goiter" and which apparently interferes with the concentration of iodine in the thyroid gland by a process of competitive inhibition. While thiocyanates as such do not appear to be involved in rapeseed meal toxicity these compounds in foliage may be related to the ultimate goitrogenicity of the seeds of *Brassica* species.

Of particular interest with regard to rapeseed is that group of substances which exert antithyroid activity through interference with the organic binding of iodine. The coupling of two iodinated tyrosine molecules appears to be the most sensitive stage but iodination of tyrosine probably is also impaired. Compounds in this group include the thionamides, aniline derivatives and oxazolidinethione. The only isothiocyanates having significant antithyroid activity are those capable of cyclizing to form oxazolidinethione.

There is evidence that several of the antithyroid substances found in *Brassica* seeds can inhibit metabolism in tissues *in vitro* and therefore without direct involvement with thyroxine (4, 10 and others). However, Greer et al. (36) claim that few if any of these compounds are capable of blocking the action of thyroxine once it has left the thyroid. The authors note possible exceptions with the comment that certain thionamides may affect the metabolism or retard the breakdown of circulating thyroid hormone. For instance, rats treated with propylthiouracil and simultaneously with a "compensating" level of thyroxine develop goiters. This has been explained as failure of circulating thyroxine to be converted to an "intracellularly active" form, one consequence of which is increased production of TSH by the pituitary.

Aside from goitrogenesis, growth inhibition as a consequence of thyroid malfunction has been a frequently observed result of rapeseed toxicity. Since the early observations of Viehover et al. (75) many investigators have confirmed these results for young animals of numerous species (5). The recent literature indicates that the substitution of solvent- for expeller-processed meal has alleviated the problem of growth inhibition to

a marked extent. It is possible that improved temperature control in the oil extracting plants, resulting in protein of higher biological value, is responsible for part of the noted improvement (26). Altered activity of the enzyme myrosinase may also be involved.

While growth retardation occurred in chicks fed levels as low as 10% of expeller meal (5), a recent report by Clandinin (23) on the feeding value of solvent meal suggested that its growth-promoting value approaches that of soybean meal when incorporated in chick diets at levels of 10 or 15 percent. Hussar and Bowland in 1959 (40) observed that the substitution of soybean by rapeseed expeller meal in growing swine rations to the extent of 10% of the total ration caused significant reductions in growth rate and feed efficiency. However, the substitution of 15% solvent meal had no effect on feed utilization although some growth depression was experienced (51). Swine carcass characteristics appeared to be unaffected by rapeseed meal feeding.

Growth inhibition has been used in mouse studies (6, 7, 8, 11) as an index of toxicity in rapeseed meal and it has been shown that isothiocyanates and oxazolidinethione, enzymatically liberated from their parent glucosides, have about equal effects on growth rates. For instance, 0.1% isothiocyanate plus oxazolidinethione in the diet resulted in extreme growth depression in mice regardless of the ratio of these two compounds; a dietary level of 0.2% proved lethal but it was observed that males were affected somewhat more severely than females.

Adverse effects have also been observed by the senior author when 7% rapeseed meal (of either *B. campestris* L. or *B. napus* L. origin) was included in rations fed to pregnant gilts. Litter size was reduced, lactation was impaired and the gilts displayed physical weakness after farrowing. Similar responses were observed earlier with mice when first-litter immature females were unable to tolerate the added stress of lactation when diets containing 30% rapeseed meal were fed. The activity of myrosinase and the specific amounts of isothiocyanate and oxazolidinethione were not determined in these studies.

Modification of Feeding Value of Rapeseed Meal

Extraction Procedures

Improvements in the feeding value of rapeseed meal following aqueous and alcohol extraction have been reported (1, 6, 39). Bell (6) found that acid hydrolysis resulted in little if any improvement in toxicity. Schwarze in 1949 (69) and Goering in 1961 (32) reported on removal of the mustard oils from rapeseed meal by moistening the ground seeds with cold water, adding myrosinase if necessary and finally steam stripping to remove the volatile "oils". Oxazolidinethione, being non-volatile, remained in the meal. Goering digested the meal at 45-55 C with water in the ratio of six to

eight volumes of water to one volume of rapeseed meal. The risk of impairing the quality of the rapeseed oil by so treating ground rapeseed has been discussed by Clandinin (23).

Belzile and Bell (10), using both *B. campestris* and *B. napus* petroleum-ether-extracted meals, studied the effects of hot (90 C) water extraction on isothiocyanate and oxazolidinethione contents (77, 78) and on toxicity as revealed by mouse bioassays. Meals thus treated were found devoid of myrosinase and there was no evidence of thioglucoside hydrolysis having occurred. The extraction of the meals with hot water resulted in about 20% of the original meals going into "solution" and in some apparent alteration of the toxic constituents. From 27 to 48% more isothiocyanate and 8 to 11% less oxazolidinethione were recovered in the residues and extracts than existed in the original meals. This resulted in a net increase in apparent toxicity of about 3% for Swedish (summer, *B. napus*) and 34% for Polish (summer turnip, *B. campestris*) meal. In subsequent bioassays with mice fed diets containing a total of 0.1% isothiocyanate plus oxazolidinethione the extracted *residues* of the two types of meal gave similar responses and confirmed the chemical appraisals of potential toxicity by effecting a 10% reduction in growth. The *extracts* proved less toxic than anticipated from the chemical assays, especially in the case of *B. campestris*, where isothiocyanate predominated, in contrast to *B. napus* where isothiocyanate occurred at half the concentration found for oxazolidinethione.

Dry Heat

Solvent-extracted meals were subjected to 12 hours' oven treatment at 135 C and tested for toxicity as indicated above (11). Such treatment destroyed myrosinase activity but preliminary studies indicated that the enzyme was inactivated rather slowly since some activity remained after 6 hours at 135 C. There was no significant reduction in the amounts of isothiocyanates or oxazolidinethione following cooking but these remained in glucoside form. When fed to mice in bioassay tests, dry-heated meals were markedly superior to unheated meals, thus confirming the role of the enzyme in the toxicity picture (9).

Steam Pressure

Similar meals (11) were subjected to steam autoclaving for 15 min at 1.2 kg/cm^2 (17 lb/inch^2) pressure in a pre-heated autoclave following which the meals were dried *in vacuo* at 50 C. Under these conditions myrosinase was rapidly destroyed without any apparent effect on the thioglucoside content of the meal. Feeding steam-treated meals to mice as 10 to 20% of the diet allowed normal growth and feed consumption whereas untreated meal, containing active enzyme, permitted only 10% of normal growth rate. It has been shown that the enzyme myrosinase *per se* produces no adverse effects when fed in diets free of thioglucosides (9).

In other studies these workers compared 0.6 and 1.2 kg/cm^2 (9 and 17 lb/inch^2) autoclaving for periods of up to 2 hours' duration. Solvent-extracted, enzyme-free commercial rapeseed meal was used. It was found that the amount of pressure used had a marked effect on the rate of disappearance of isothiocyanates and oxazolidinethione. In effect, doubling the pressure doubled the disappearance rate but oxazolidinethione disappeared twice as fast as isothiocyanate. At the higher pressure over 90% of the original oxazolidinethione and 75% of the isothiocyanate had disappeared in 2 hours.

Bioassays were conducted on meals that had been autoclaved for 0, 16, 30, 60, 120 and 180 min at 1.2 kg/cm^2. The meals were also tested in rations containing 0.15% purified myrosinase. In the absence of added enzyme, growth rates were near normal in all cases but when myrosinase was reincorporated into diets containing meals that had received 15 or 30 min autoclaving to permit thioglucoside hydrolysis, gains were significantly depressed. Meals treated for 60 min or longer produced normal gains regardless of presence or absence of enzyme. It is thus evident that apparent destruction of toxic factors by extended steam treatment under pressure was confirmed by animal tests.

Steam Stripping

Commercially produced enzyme-free rapeseed meals were placed in a laboratory scale steam stripper which accommodated 300 g of meal, maintained a temperature of 110 C and permitted steam passage through constantly revolving meal at a rate designed to yield about 12 ml of steam condensate per minute (10). This treatment resulted in steady reduction of isothiocyanate content resulting in almost complete removal by 2 hours. About 10% of the oxazolidinethione remained after 3 hours of steam stripping. As in the case of autoclaved meals, the bioassays confirmed the chemically assayed toxicity and also confirmed the inability of added myrosinase to depress growth response in mice fed meals steam stripped at least 1 hour.

In studies designed to assess the nutritional value of the protein of rapeseed meals treated by autoclaving or steam stripping the same authors observed gradual deterioration in protein quality as time of steam treatment was extended. In fact, meals that were autoclaved for 2 hours at 1.2 kg/cm^2 did not support growth when used as the only protein source in an otherwise adequate diet. These observations may reflect lysine destruction (24) (*see* Chapter 2) but no lysine determinations were made.

Effects of pH and Temperature of Wet Enzyme-free and Enzyme-active Meals on Subsequent Value of the Meals

Buffered solutions of pH 3, 6 or 9 were mixed with meals of *B. napus* origin and stirred continuously for 1 hour at either 22 or 50 C. The wet mash was then either filtered and washed twice with additional buffer solution and then air dried or else dried without filtration (11).

Soaking the meal had little effect on chemically assayed toxicity in the absence of myrosinase but removal of the filtrate eliminated over 80% of the toxic compounds. By contrast, if myrosinase was present during the conditioning period there was a loss of about $\frac{1}{3}$ of the toxic material after an hour's soaking at pH 3, $\frac{1}{2}$ at pH 6 and about $\frac{2}{3}$ at pH 9, even though no filtration was involved. When enzymatically-active meals were filtered before drying those processed at pH 9 were slightly less toxic than those treated at pH 3 and 6 but they all contained more mustard oils than did the extracted residues resulting from enzyme-free meals. Conditioning temperature had no effect.

In general, the bioassay results confirmed the chemical assays but there was some evidence that enzymatic activity at pH 6 or 9 resulted in lower quality meal than was indicated by isothiocyanate and oxazolidinethione assays. Thus it appears that the more rapid destruction of mustard oils at higher pH may simply have represented partial transformation into related toxic compounds not detectable by the chemical methods employed. It seems doubtful, therefore, that adjustment of pH for modification of enzyme activity offers much promise in detoxification procedures.

Summary

The development of growth-inhibiting properties in rapeseed meal appears dependent upon hydrolysis of thioglucosides into isothiocyanates (3-butenyl and 4-pentenyl) and oxazolidinethione. The hydrolysis can be effected by the enzyme myrosinase, normally present in unheated rapeseed and more recently shown to occur in the gastrointestinal tract, where it is produced by certain bacteria, especially by *E. coli* and *A. aerogenes*.

Oxazolidinethione appears to be the compound primarily, if not entirely, responsible for goitrogenicity. However, it has been shown that isothiocyanates can cyclize to form oxazolidinethione. This may account for the rather similar effects of the two types of rapeseed compounds but the nature of metabolic interference by isothiocyanates needs clarification. These compounds have been shown to depress a number of metabolic reactions but are claimed to be incapable of blocking thyroxine activity once the hormone has been released from the thyroid. Whatever the final explanation may be, the variable responses obtained from dietary supplementation with iodine, iodinated casein and thyroxine indicate that the action of the rapeseed compounds is more complicated than interference with thyroxine synthesis or release. Thus it is of special interest to recall the postulation that natural antithyroid compounds may exist which may reduce the efficiency of circulating thyroxine, thereby depressing metabolism, leading to increased production of TSH and to development of goiter.

Methods of processing rapeseed in Canada result in production of myrosinase-free rapeseed meal containing unhydrolyzed thioglucosides. Such meal apparently is free of most of the undesirable properties if

myrosinase is not reintroduced by other dietary ingredients or by intestinal bacteria. The potential antithyroid activity can be markedly reduced by heating, as revealed by the findings that most of the thioglucosides can be destroyed by 2 hours of either autoclaving at a steam pressure of 1.2 kg/cm^2 (17 lb/inch^2) or steam stripping at 110 C. Autoclaving resulted in severe damage to protein quality but steam stripping showed promise as a means of alleviating the risk of thioglucoside hydrolysis during digestion in the animal body.

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CHAPTER 5. FEEDING VALUE OF RAPESEED MEAL FOR RUMINANT ANIMALS

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Introduction

Rapeseed meal is a relatively new protein supplement for ruminant animals in Canada, although it has been used extensively in other parts of the world for many years. It was regarded with some disfavor among cattle and sheep producers until fairly recently because it was considered to be unpalatable and to have certain growth-depressing and goitrogenic effects when fed liberally. However, as discussed in Chapters 1 and 2, the varieties of rape (largely Polish type, *Brassica campestris*) grown in Canada now contain less of the glucoside oxazolidinethione and the method of extracting the oil from the seed has changed largely from expeller to solvent extraction. The enzyme myrosinase, which is present in rapeseed and which splits the glucosides into the active goitrogenic substances, requires moisture for this reaction (*see* Chapter 4). In modern processing, the enzyme is destroyed in initial processing by steam heat and the goitrogenic factors are left bound in the original glucoside complex.

Considerably less detailed research has been conducted with ruminant animals on the digestibility, acceptability, efficiency of utilization, and comparative value of rapeseed meal than with pigs, poultry and laboratory animals. Because ruminant animals have not been so adversely affected by the so-called goitrogenic factors may be a reason (4, 5, 6). It had been generally considered that rapeseed meal was less palatable and less readily digestible than many of the other more commonly used high-protein meals of plant origin (e.g., soybean, sunflower, linseed meal). This review is a critical evaluation of rapeseed meal in comparison to other high-protein meals for ruminant animals.

Rapeseed Meal for Young Ruminant Animals (Birth to 6 Months)

Very little detailed information is available on the value of rapeseed meal for young calves and lambs in comparison with other extracted meals from oilseed plants. Burkitt (8) reported that lambs digested a rapeseed meal – grass hay ration to the same extent as a linseed meal – grass hay ration. The rapeseed meal was not as palatable, initially, as the linseed meal. Clark and Bezeau (10) fed three groups of Holstein dairy calves

limited whole milk (3.6 kg/day) to 28 days of age along with alfalfa hay and a calf starter containing 10% linseed meal to one group, 10.4% expeller-extracted rapeseed meal to a second group, and 10% solvent-extracted rapeseed meal to a third group. The starter and alfalfa were fed until the calves were 16 weeks old. Rapeseed meal made up about 6% of the dry matter of the total ration. Although the calves initially did not eat the starter containing rapeseed meal as well as that containing linseed meal, there were no differences between groups in their consumption of starters or rate of growth to 16 weeks of age. Palmer (19) reported that one group of ram lambs weaned at about 5 months of age and offered rapeseed meal *ad libitum* plus native pasture did not consume the rapeseed meal as readily as did a group offered linseed meal. However, no abnormal symptoms were noted among the lambs fed the rapeseed meal and the two groups gained the same weight.

Hornoiu and Cadantu (13) stated that rapeseed meal was unpalatable to cattle and sheep but that they would consume large quantities of it. They recommended limiting milk cows to 0.5 kg daily, young cattle and adult sheep to 0.3 kg daily and young sheep to 0.2 kg daily although both calves and sheep would consume up to 0.7 kg daily. It is not stated clearly whether this recommendation is based on experimental evidence or on their observations among livestock fed these amounts.

Rapeseed Meal for Growing and Fattening Animals

Seale (21) compared linseed meal, sunflower meal, mustard seed meal and rapeseed meal when these meals made up 8 to 10% of a grain mixture for fattening steers. The grain mixture was fed *ad libitum* after the first 6 weeks. The experiment continued for 140 days. Mature prairie hay was fed as roughage. At the beginning of the feeding period the animals which were fed the grain mixture containing rapeseed meal and mustard seed meal did not consume their rations as promptly as those fed the other meals. The group which was fed linseed meal gained an average of 0.98 kg per day, and the other three groups gained an average of 0.86 kg per day. There was no difference in efficiency of feed utilization between the groups receiving sunflower seed meal, rapeseed meal or mustard seed meal.

Burkitt et al. (9) fed pregnant beef cows, yearling cattle, and weaned calves low protein roughages (grass hay and wheat straw) supplemented with 0.4 kg of linseed meal or rapeseed meal per animal daily. Although the rapeseed meal was relatively less palatable than the linseed meal, all groups consumed their allotment of rapeseed meal and made gains similar to those fed linseed meal. The animals consumed the linseed meal more readily and quickly than those fed rapeseed meal. If the linseed meal and the rapeseed meal had been fed *ad libitum* rather than in set amounts based on need, the animals fed linseed meal would probably have consumed more than those fed rapeseed meal. Masson (16) stated that rapeseed meal has

been fed satisfactorily at the Centre National de Recherche Zootechnique, in France, as 35% of the concentrate portion of the ration for fattening steers (4 kg of concentrate was fed daily per animal). He emphasized that the meal should be dry when fed and that it should be introduced into the ration gradually.

Rapeseed Meal for Breeding Animals and for Reproduction

Bell and Weir (4) fed four groups of 22 ewes each during pregnancy with alfalfa and four groups with marsh hay (predominantly *Carex* species). One group of those fed alfalfa and one group of those fed marsh hay received 0.2 kg daily of one of the following supplements: linseed meal, rapeseed meal and mustard seed meal, one lot was fed alfalfa hay, and one lot was fed marsh hay without protein supplement. The ewes fed the rapeseed meal and mustard seed meal consumed their meals less rapidly than those fed linseed meal but always consumed their daily allotment. The three meals were equally effective in terms of weight gain of the ewes and birth weight of the lambs. No thyroid enlargements were noted among the ewes or the lambs from ewes fed rapeseed meal.

Bezeau et al. (7) fed rations which contained 10 and 20% rapeseed meal and 10 and 20% linseed meal to groups of pregnant and lactating ewes in comparison with similar groups fed no protein supplement. The rations were composed of 50% chopped grass hay and 50% pelleted grain mixture containing the rapeseed or linseed meal. The hay and grain mix were fed separately. In the second experiment, rations containing 10, 20 and 30% rapeseed meal were compared with one containing 10% linseed meal. The rapeseed meal was from a mixture of summer and summer turnip varieties (*Brassica napus* and *B. campestris*), extracted by the expeller process. It contained 2.09 mg of isothiocyanates and 2.41 mg of oxazolidinethione per g of meal. No palatability problem was encountered when rations containing 10 and 20% rapeseed meal were fed but there was a problem with the ration containing 30% rapeseed meal. There were no important differences between the groups fed rations with 10 and 20% linseed meal and 10 and 20% rapeseed meal in terms of weight gains, and wool production of the ewes and in birth weight and growth of the lambs. The ewes fed the ration containing 30% rapeseed meal consumed less feed than those fed the other rations, gained less weight, produced less wool and smaller lambs that gained less rapidly. No enlarged thyroid glands were noted among any of the ewes or lambs.

Rapeseed Meal for Milk Production

Jarl (14) fed cows 2.5 kg daily of an oilcake mixture containing 0, 25 and 50 to 60% rapeseed meal. The average daily consumption of rapeseed meal was 1.2 to 1.4 kg when the oilcake mixture contained 50 to 60% rape-

seed meal. This represented about 9% of the dry matter intake. The rapeseed meal used in these experiments contained an average of 1.6% ether extract, 36.6% protein and 0.17% mustard oil. The cows produced an average of 16 kg of 4% fat-corrected milk daily. The cows that were fed 0 and 25% rapeseed meal in the oilcake mixture produced 0.5 kg more milk daily than the cows that received 50 to 60% rapeseed meal in the oilcake mixture. The cows that received rapeseed meal produced milk of slightly lower fat content, but gained more weight than the cows that received no rapeseed meal. The fat produced by cows receiving rapeseed meal was of higher iodine number than that by cows receiving no rapeseed meal. Palatability of the rapeseed meal was not a problem as soon as the cows became accustomed to it. The author stated that Swedish rapeseed meal was a good high-protein concentrate for dairy cows and could be fed at a daily amount of at least 2 kg per cow but that it should always be fed dry.

Seale (20) fed two groups of six milking cows, 3 to 5 months postpartum, a ration of hay and grain mixture which contained either 20% rapeseed meal or 20% linseed meal. The daily amount of hay fed to each cow was determined by her body weight and the amount of grain mixture by her milk production. Each experimental period lasted 21 days and was preceded by a 10-day preliminary period. Average daily milk production during the experimental period was 11 kilograms. When the cows received the ration containing rapeseed meal they produced about 0.2 kg more milk per cow daily (not statistically significant) of the same butterfat content. There was no difference in palatability between the rations or in the taste and odor of the milk produced.

Nordfeldt (18) compared rapeseed meal of low and high fat content (1.6 and 7.0%) with soybean meal when fed to dairy cows in digestion and feeding experiments. There was no difference between groups in milk production. Feeding rapeseed meal at a daily rate of 1.8 kg resulted in a small but significant increase in iodine number of the fat. There was no difference in odor or taste of the milk produced. Rapeseed meal was as palatable as soybean meal. The low fat rapeseed meal used contained 37.9% protein, 9.9% fiber and 0.4% mustard oil. The author suggested that feeding 1.5 kg per cow daily is practical.

Homb et al. (11) fed two groups of 11 cows during an 11-week period the same rations except that one group received a concentrate containing 5% rapeseed meal and the other group a concentrate containing 5% linseed meal. There were no significant differences between groups in milk yield, condition of the animals or consistency of the feces. The inclusion of rapeseed meal in the concentrate mix did not taint the milk. In further experiments (12) when groups of 12 cows were fed either 5 or 10% rapeseed meal (250 and 395 g daily, respectively) in the concentrate mix or an

equivalent amount of herring meal or soybean meal there was no difference in milk yield, fat content of the milk or weight gain of the cows. The iodine number of the milk fat increased slightly when rapeseed meal was fed. Rapeseed meal had no effect on the palatability of the milk.

In an experiment at the University of Alberta, Asplund (1) fed rations, during 12-week periods, to milking cows in which rapeseed meal made up 0, 10 and 20% of the dry matter content of the total ration. All rations contained the same protein content (rapeseed meal replaced linseed meal in the ration). Expeller-processed meal was used. Some cows rejected at first the concentrate mix containing rapeseed meal but all consumed their daily allowance after the first week. The cows that received 10% rapeseed meal produced as much milk as those that received linseed meal, but those that received 20% rapeseed meal declined in milk production almost twice as fast as the controls (46 vs 26% over the 12-week period). Average production was 16 kg per day. There was no difference between groups in the flavor of the milk. Feeding rapeseed meal at 20% of the total ration did not affect the protein-bound iodine content of the blood during an 11-week period. In a further experiment (2,3) a concentrate mix containing either 10% linseed meal or 10% rapeseed meal was fed to dairy cows on pasture at 1 kg per 6 kg of milk or 1 kg per 12 kg of milk produced during a 13-week period. The cows produced an average of 21 kg of milk daily. The concentrate mix which contained rapeseed meal was as palatable as that which contained linseed meal. There was no difference in milk production caused by the substitution of rapeseed meal for linseed meal. Solvent-extracted rapeseed meal was used in this experiment.

Witt et al. (23) fed 22 milk cows, with an average milk production of 19 kg, a ration in which the concentrate mix contained 25% rapeseed meal. Daily intake of the rapeseed meal which contained 1.1% fat was between 1.25 and 1.36 kilograms. The ration which contained rapeseed meal was well accepted by the cows and increased the average daily milk yield per cow by 0.4 kg with no adverse affect on the fat content.

Larsen (15) reported that rapeseed meal which did not contain poisonous seeds or which did not contain large quantities of mustard oil could be used successfully in limited amounts as a feed for milk cows. He further stated that rapeseed meal from seed grown in Europe had a mustard oil content which seldom exceeded 0.20 to 0.25 percent. Meal prepared from such rapeseed is safe as a feed for milk cows. In early Danish experiments, dairy cows had been fed 3 to 4 kg of rapeseed meal daily with no ill effects except diarrhea. In more recent experiments cows received as much as 2.2 kg of meal daily. Although some difficulty was experienced initially in getting the cows to consume this amount of rapeseed meal (rapeseed meal made up 40% of a concentrate mixture), the cows consumed the quantity given to them after the first week.

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Masson (16) stated that rapeseed meal had been used satisfactorily as 30% of the concentrate portion of rations for milk cows. Four kg of concentrate was fed daily. He cautioned that rapeseed meal should be introduced gradually into a ration.

Although ruminant animals do not seem to be affected by the potential goitrogenic factors in rapeseed meal to the same extent as poultry, pigs and laboratory animals, the question has been raised as to whether these factors can be transferred from the feed to the milk of dairy cows. Virtanen et al. (22) in Finland, studied this question and concluded that only approximately 0.05% of the (-)-5-vinyl-2-oxazolidinethione (previously known as (1)-5-vinyl-2-thiooxazolidone) contained in the ration was found in the milk, an amount so small that milk from cows fed large quantities of rapeseed meal rich in oxazolidinethione would have insignificant amounts. Similar results were obtained with thiocyanates. Virtanen et al. (22) point out that the reason for this was that the goitrogens were destroyed in the rumen and not absorbed into the blood stream. This may explain why ruminant animals have not shown enlarged thyroid glands or other symptoms when fed fairly large amounts of rapeseed meal.

Composition and Digestibility of Rapeseed Meal

Data on the chemical composition of rapeseed meal are shown in Chapter 3. Although the varieties of rapeseed grown in many areas of the world have changed in recent years and the method of processing the meal has changed almost entirely from an expeller to solvent extraction (at least in Canada and Western Europe), the digestibility of rapeseed meal has not changed appreciably. Nehring and Schramm (17) reported that rapeseed meal contained 29.2% digestible protein and linseed meal 30.7% (no digestibility coefficients listed), whereas the corresponding starch values were 60.7 and 58.0 percent. Bezeau et al. (7) found that the digestibility of the dry matter and protein was higher in a ration which contained 20% linseed meal than in a ration which contained 20% rapeseed meal (64 vs 61% for dry matter and 73 vs 66% for protein). The two rations contained the same percentage of protein. Jarl (14) reported digestibility coefficients for the organic matter of rapeseed meal as 76%, ether extract 98%, crude fiber 25%, nitrogen-free extract 78% and crude protein 83 percent. The rapeseed meal that was fed in Jarl's experiment contained 1% ether extract, 0.17% mustard oil and 35% protein. Nordfeldt (18) reported that dairy cows fed rapeseed meal containing 37.9% protein, 1.7% fat, and 9.9% crude fiber digested approximately 76% of the organic matter and 85% of the protein. Burkitt (8) compared the digestibility of a grass hay - rapeseed meal ration to a grass hay - linseed meal ration when fed to lambs (average wt 34 kg). Both rations contained 11.4% protein. There was no significant difference in the digestibility of the dry matter of the rations or the individual nutrients in the two rations.

General Recommendations

As pointed out in the Introduction to this chapter, rapeseed meal produced by solvent extraction and by preheating to destroy myrosinase activity is a much superior meal to that common in Canada and many countries of the world 10 to 20 years ago. Introduction of new varieties of rape also has had an effect on the quality of the meal produced. Even when the meals produced in North America and Europe 20 or more years ago were fed to ruminant animals very few adverse effects were noted. Present evidence as reviewed here indicates that solvent-extracted rapeseed meal similar to that produced in Canada can be considered to be equivalent in nutritional value on an equivalent protein basis to other high-protein meals of plant origin such as linseed and soybean meals when it makes up to 10% of the total dry matter of the ration. Since only under unusual circumstances will rapeseed meal be fed in amounts exceeding 10% of the total ration no adverse effects on gains, milk production or reproduction should be expected. Rapeseed meal when forming more than 10% of the total ration, or a component of part of the ration, may be less acceptable initially to ruminant animals of all ages than soybean, linseed or sunflower meals. However, ruminant animals become accustomed to rapeseed meal fairly rapidly and no palatability problems are usually encountered after approximately one week from when it is introduced into the ration.

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CHAPTER 6. FEEDING VALUE OF RAPESEED MEAL FOR SWINE

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Introduction

As swine are monogastric animals, they must be supplied with a source of protein that meets both their quantitative requirements for protein and their qualitative requirements for essential amino acids. The amino acid composition of solvent-extracted rapeseed meal as compared with other vegetable protein sources is given in Chapter 3. When these composition data are compared to the amino acid requirements of the young pig [U.S. N.R.C. Nutrient Requirements for Swine (27)] the potential quality of rapeseed meal is found to be similar to that of soybean meal. There is the suggestion, however, from some early studies with pigs, that the nutritional value of rapeseed meal may not parallel its potential based on average analysis. These experiments will be discussed later in this chapter.

In recent years there has been a major change in processing methods used for rapeseed meal (*see* Chapter 2). Meals that are now available are either solvent extracted or solvent extracted following partial expeller extraction. As discussed in Chapters 2 and 3 the present meals have a higher level of amino acids, particularly lysine, than former meals. In addition the average protein, fat and crude fiber of 40.5, 1.1 and 9.3% respectively from solvent meals are markedly different to average values given by Morrison (26). Therefore the actual value of rapeseed meal for swine feeding must be considered in relation to the meals at present available.

Starting Rations for Pigs up to 25 kg Liveweight

Feed Intake

A major criterion in evaluating rations for creep feeding, pre-starting and starting of pigs up to 8 to 10 weeks of age or 25 kg in weight is the provision of a ration that is acceptable and therefore consumed at high levels to provide a high energy intake. It has been observed that rapeseed meal is often not liked by livestock, probably because of its sharp bitter taste (26). Studies with young pigs have given variable results regarding acceptability or palatability of rations containing rapeseed meal. Bowland (8)

noted that when an alternate ration was available, pigs did not accept pre-starter rations containing 2 to 10% of expeller-processed rapeseed meal of either Argentine (*Brassica napus*) or Polish (*Brassica campestris*) type. When pigs at 3 weeks of age, averaging 6 kg in weight, were offered a ration containing the same Argentine-type meal with no alternative available there was no evidence of appetite depression (9,20). The group-fed pigs receiving 10% rapeseed meal in the ration consumed 0.69 kg per day as compared to 0.66 kg per day for those receiving a ration with soybean meal substituted at an equivalent protein level. In later studies (12,23), with group-fed or individually-fed pigs weighing 9 to 23 kg there was no significant influence on feed consumption when all of the soybean meal in a basal starting ration containing 13% soybean meal was replaced by isonitrogenous levels of solvent-extracted Polish-type rapeseed meal.

Seale (32) found that inclusion of 13 to 26% rapeseed meal to replace $\frac{1}{2}$ or all of the linseed meal in a ration for pigs from 18 to 36 kg in weight had no adverse effect on feed consumption. In more recent studies at the University of Manitoba (34) rapeseed meal containing 5.15 mg isothiocyanate and 3.45 mg oxazolidinethione per g of meal was fed to 14 kg pigs for a 3- to 4-week period. This rapeseed meal was compared as a replacement on a protein-equivalent basis for 50 to 100% of the protein contributed by soybean meal which represented 10.4% of the ration. There was a depression in average daily feed intake from 1.11 kg per day for the soybean meal ration to 0.90 kg per day when rapeseed meal replaced 100% of the soybean meal.

Lack of palatability does not seem to be a major factor affecting the use of rapeseed meal in starting rations. The addition of 10% or over of rapeseed meal to the ration of young pigs may reduce ration acceptability as evidenced by lower feed consumption, but this is a level above that recommended in normal ration formulation for young pigs.

Rate of Gain and Efficiency of Feed Utilization

As discussed by Clandinin et al. (14) and others, and as outlined in Chapters 2, 3 and 4, the growth promoting value and goitrogenic properties of rapeseed meal are influenced by factors such as variety of the seed and environmental conditions under which it is grown, processing methods, and physiological aspects such as sex and age of animals.

In studies at the University of Alberta (9,20) with expeller-processed meal, average daily gain was not significantly depressed when group-fed pigs from 6 to 16 kg liveweight received 2 or 10% rapeseed meal in substitution for soybean meal. With individually-fed pigs of similar weight, rate of gain was depressed 0.06 kg per day when 10% rapeseed meal was fed. Efficiency of feed utilization (kg feed per kg gain) was not influenced in this study.

In a later experiment with solvent-extracted rapeseed meal (12,23), the substitution of rapeseed meal for 25% of the soybean meal in the

ration had no effect on rate of gain for group-fed pigs from 9 to 23 kg liveweight but 50 or 100% substitution reduced rate of gain 0.07 and 0.10 kg per day respectively. The addition of 0.2% L-lysine to the ration containing the highest level of rapeseed meal did not improve gain. Efficiency of feed utilization was not influenced by any level of rapeseed meal.

In Seale's experiment (32) rapeseed meal did not influence gain or feed/gain ratio of pigs from 18 to 36 kg liveweight. In a later Manitoba study (34) with younger pigs there was a depression in rate of gain when rapeseed meal replaced 50 or 100% of soybean meal in the ration. This reduced gain was related to feed consumption so that efficiency of feed utilization was not adversely affected by rapeseed meal. Rates of gain on the rapeseed meal-containing ration were similar to those obtained when sunflower meal was substituted at equivalent levels but efficiency of feed utilization was superior for the rations containing rapeseed meal.

With young weanling or pre-weanling pigs from 3 weks of age up to weights of 25 kg, the rate of gain may be depressed when rapeseed meal is compared with soybean meal as a protein supplement at levels above 4 to 5% of the total ration, although levels of rapeseed meal up to 10% of the ration are normally acceptable. Any growth depression occurring is usually closely related to reduced feed intake and efficiency of feed utilization is not adversely influenced by substitution of rapeseed meal for soybean meal in the ration.

Growing and Finishing Rations for Market Pigs from 25 to 90 kg Liveweight

Feed Intake, Gain and Feed Conversion

Studies with rapeseed meal as a protein supplement for growing and finishing pigs above 25 kg in weight are more extensive than those with younger pigs. As mentioned in the Introduction to this chapter, many of the early studies are largely of historical interest because of the changes in processing methods in recent years.

In studies in Germany in 1937, Frölich and Haring (18) satisfactorily fed up to 200 g of rapeseed meal per head per day to young growing pigs, but reported that the meal was unsatisfactory for finishing pigs. However, in a second study (19), the same authors indicated that rape meal could replace a portion of the fishmeal in the ration of fattening pigs. For a liveweight gain of not less than 600 g per day, they recommended that the daily amount of rape meal must not exceed 150 g if the mustard oil content is low (0.11-0.13%) or 100 g if it is high. In a small-scale experiment, Cook (15) in 1941 found that the substitution of rapeseed meal for half the meat meal in a standard ration gave poor results.

In 1952, Seale (32) compared expeller-extracted rapeseed meal and linseed meal as the sole sources of supplemental protein in pig rations based

on oats, wheat and barley. From 36 kg to market weight of 91 kg, pigs receiving rapeseed meal as the sole source of protein made slower and less efficient gains than those receiving linseed meal, even though rapeseed meal had no effect on performance when fed up to 36 kg liveweight. When rapeseed meal replaced only half of the linseed meal, the gain and feed/gain ratio were comparable to those obtained with linseed meal. The author suggests that inclusion of rapeseed meal may have decreased palatability of the ration. However, daily feed consumption varied by only 0.1 kg per day between lots. The pigs receiving rapeseed meal consumed their feed more slowly and were inclined to waste feed.

In 1953 Seale (33) reported further studies to determine the optimum level at which rapeseed meal should be incorporated in a protein supplement used with an oat–wheat ration. The 35% crude protein supplement contained 20% meat meal, 20% alfalfa meal and 60% linseed meal with rapeseed meal replacing $\frac{1}{3}$, $\frac{2}{3}$ or all of the linseed meal. The results indicated that rapeseed meal can be included as a replacement for linseed meal in a protein supplement of the type used without significant reduction in feed intake, rate of gain or efficiency of feed utilization.

In studies by Nordfeldt et al. (28) rapeseed meal was evaluated with isocaloric and isonitrogenous diets fed to pigs. Daily gain was not significantly reduced when rapeseed meal was fed as 13.0, 9.5, 8.0 or 0% of the ration from 30, 40, 50 and 75 kg liveweight respectively. In a second experiment both untreated and water-extracted rapeseed meals were fed at levels of 17.5, 10.0, 7.5 and 3.1% of the ration when pigs reached 30, 40, 50 and 90 kg liveweight. Growth depression occurred in this experiment but was less for the water-extracted meal.

Clausen in Denmark, as described by Fevrier (16), reported a marked decrease in feed consumption in growing pigs receiving rapeseed meal and milk, rapeseed meal and meat meal or straight rapeseed meal in comparison with milk. These results were based on 24 pigs per lot started on experiment at 24 kg liveweight. Rate of gain and efficiency of feed utilization were depressed in the rations containing rapeseed meal as compared to the control ration containing milk as the source of supplemental protein.

In 1957, Fevrier (16) reported on a series of experiments in which swine were used as experimental animals to test the supplemental value of four lots of rapeseed meal, part of which was treated by the André process, which involved a combination of heat and of hot water extraction by use of active steam. The rations contained 10 to 25% rapeseed meal with the protein balanced with 5% meat meal and, in some cases, peanut meal. Gain was lower when the highest level of rapeseed meal was fed. The hot water treatment was not generally effective. Further studies were conducted using meal that was more intensively steam-treated than in the former case. There was a marked improvement in feed intake, average daily gain and feed conversion from the meals that were more intensively treated but the gain was still inferior to that expected from other meals.

Hussar and Bowland (20) fed 2 or 10% expeller-extracted Argentine-type (*B. napus*) rapeseed meal to either group-fed or individually-fed market pigs and found that the 10% level of the meal depressed rate of liveweight gain and in some cases reduced efficiency of feed utilization. Feed consumption was not adversely influenced by the levels of meal used in the diets. The 2% level of rapeseed meal did not exert any demonstrable effects on any criteria measured.

In studies with solvent-extracted rapeseed meal (12,23), the meal was substituted on an equivalent protein basis for 0 to 100% of the soybean meal in diets for pigs. At the highest level of feeding, rapeseed meal represented 66 to 76% of the total supplemental protein (15.6% of the total ration for growing pigs and 9.6% of the ration for finishing pigs). Replacement of 25% of the soybean meal by rapeseed meal did not influence feed intake, rate of gain or efficiency of feed utilization but when 50 or 100% of the soybean meal was replaced by rapeseed meal the rate of gain and efficiency of feed utilization were depressed for group-fed pigs from 23 to 50 kg liveweight but not for individually-fed pigs. Addition of 0.2% L-lysine to the ration containing 100% rapeseed meal failed to influence rate of gain and significantly depressed efficiency of feed utilization.

Myrosinase Activity in the Meal

The enzyme myrosinase may play a part in the growth-depressing properties of some samples of rapeseed meal. It is pointed out in Altschul's review (1) that this enzyme catalyzes decomposition of sinigrin and sinalbin with the formation of mustard oils. In a recent paper Bell (6) has studied the feeding value for growing-finishing swine of myrosinase-free solvent-extracted rapeseed meal and of the effect of adding a source of myrosinase to diets containing this new-process meal. The meal was of *B. campestris* L. origin and although free of active myrosinase retained most of its original complement of thioglucosides.

The use of either 5 or 10% of this rapeseed meal significantly depressed feed intake and rate of gain from 23 to 46 kg liveweight while a level of 5% meal in the finishing ration fed above 46 kg liveweight had no effect on swine performance. Growth depression closely reflected feed intake levels, hence palatability of the rapeseed meal may have been involved. When ground rapeseed screenings were added as a source of myrosinase there was three times as much growth depression during the growing period as occurred in the absence of rapeseed screenings (6). Growth depression also occurred in the finishing period when rations contained 5% rapeseed meal. The author mentions that the results of this experiment confirm previous findings *in vitro* and with mice. In practice it must be recognized that there may be a problem in formulating rations free of external sources of myrosinase even if the rapeseed meal is itself processed so as to be free of active myrosinase. As discussed in Chapter 4, the enzyme myrosinase may also occur in the gastrointestinal tract where it is produced by bacteria.

Although results of experiments have varied, the general strength of evidence is that rapeseed meal, particularly solvent-processed meal, may replace up to half the supplemental protein for growing and finishing pigs with little or no adverse effect on rate of gain and efficiency of feed utilization. This recommendation supports that of Bell (4) in his review of 1954 and of the 1963 publication on "Oil and oilmeal from Canadian rapeseed" (7).

Carcass Characteristics

The addition of rapeseed to the ration of market pigs has had no consistent influence on carcass lean and fat measurements. In a Canadian study (32) in 1952, carcass grades for pigs receiving rapeseed meal in substitution for linseed meal were improved but the author mentions that this may be attributable to either the slower gain in the finishing period or the approximately 4 kg per pig lighter market weight of the rapeseed meal supplemented pigs. In a second study (33) in 1953, rapeseed meal was included as a replacement for up to 100% of the linseed meal (60% of the total protein supplement) with no effect on carcass quality as evidenced by Canadian grades or Advanced Registry (now ROP) carcass measurements and score.

Bowland (9) and Hussar and Bowland (20) observed only a limited influence on carcass quality when 10% rapeseed meal was included in the ration and no effect when 2% rapeseed meal was added to the ration of growing and finishing pigs. Loin area was significantly reduced in individually-fed pigs receiving 10% rapeseed meal in the ration but this effect was not evident for group-fed pigs. There was also a trend toward shorter carcasses from the pigs receiving 10% rapeseed meal even though they were older at slaughter and might be expected to have longer carcasses. The authors discuss results indicating that thiouracil-fed pigs have shorter carcasses than control animals so that the carcass length of the rapeseed meal-fed pigs might be related to thyroid changes resulting from rapeseed meal consumption. In the experiment of Manns and Bowland (23) carcass measurements and carcass grades were not significantly influenced by the addition of solvent-extracted rapeseed meal as a replacement for up to 100% of the soybean meal in the ration. The pigs receiving 50 or 100% rapeseed meal in replacement for soybean meal had 2.8 mm less backfat than those receiving lower levels or no rapeseed meal.

Bell (6) observed little influence of myrosinase-free rapeseed meal on carcass quality although loin area increased as the level of rapeseed meal increased in the ration. Rapeseed screenings which provided a source of myrosinase apparently depressed loin area.

The results of experiments with market pigs suggest that the levels of rapeseed meal recommended as being satisfactory for growth and feed conversion will have no adverse effects on carcass characteristics.

Reproduction and Lactation Rations

In his review in 1954, Bell (4) reported that there was insufficient data on the use of rapeseed meal to formulate recommendations for breeding stock in pigs. Morrison (26) after reviewing the information available suggested that caution in use of rapeseed meal is necessary for pregnant animals. In 1937, Frölich and Haring (18) reported that under certain conditions up to 400 g rapeseed meal per head per day was satisfactory for nursing sows. For young sows over 60 kg liveweight an allowance of 200 g rapeseed meal per day was recommended. Bell (5) obtained unsatisfactory reproduction and lactation from gilts receiving 7% rapeseed meal as a replacement for linseed meal. Number of pigs born alive, birth weights and weaning weights were low for the litters from gilts receiving rapeseed meal in the ration, with the worst results for those receiving Polish-type (*B. campestris*) meal. The gilts receiving rapeseed meal lost more weight between prior to farrowing and the end of lactation than was lost by the control gilts.

The only recent studies on the use of rapeseed meal for reproduction in pigs are those of Bowland (10) and Manns and Bowland (23) reported in 1963. Solvent-extracted rapeseed meal was substituted for 0, 25, 50 or 100% of the soybean meal in the rations from the time that gilts and boars were 3 weeks of age to the end of the first reproductive cycle including lactation. During gestation and lactation, 71% of the total supplemental protein or 12% of the total ration was represented by rapeseed meal when it replaced 100% of the soybean meal in the ration.

All gilts that farrowed and were receiving rapeseed meal in substitution for 0 or 25% of the soybean meal in the ration conceived in the first oestrus period in which they were bred at a minimum age of 230 days. There was difficulty in obtaining conception of gilts receiving the higher levels of 50 or 100% rapeseed meal in substitution for soybean meal as these gilts required an average of 2 to 2.5 oestrus cycles to conceive. Addition of 0.2% L-lysine to the ration containing the highest level of rapeseed meal was of no benefit. In simultaneous studies with rats, poor reproduction and lactation were also encountered and these results with rats have since been verified in a more detailed experiment (11). Kennedy and Purves (22) have noted a delay in development of the ovaries of immature rats fed rapeseed meal and Manns and Bowland suggest that a similar effect may have been elicited with the gilts in their study.

The number of pigs born alive was normal but litter size and weaning weights of the pigs at 5 weeks of age were low for gilts receiving rapeseed meal in replacement for 100% of the soybean meal. These results suggest lactational inadequacy.

Boars in all lots reached sexual maturity prior to 230 days of age as judged by their breeding performance and by their ability to sire litters.

The authors (23) suggest that solvent-extracted rapeseed meal should not be used at levels above 3% of the total ration of breeding females during pre-gestation, gestation and lactation.

Digestibility and Utilization of Energy and Nutrients

In studies with swine, the digestibility of dry matter and energy and the digestibility and utilization of protein have usually been similar with rations containing rapeseed meal to those of rations containing other vegetable protein supplements such as soybean meal and linseed meal. Rapeseed meal contains an average of 9.3-15.5% crude fiber, which is higher than that for most other vegetable meals, and this fiber might be expected to lower dry matter and energy digestibility.

Fevrier (16) reported a dry matter digestibility coefficient of 75% and a protein digestibility coefficient of 85% for Argentine-type (*B. napus*) rapeseed meal fed to pigs. Hussar and Bowland (21) obtained no significant effect on apparent digestibility of dry matter (average digestibility coefficient of 82%), energy (average of 81%) and nitrogen (average of 80%) in pigs weighing approximately 7, 28 or 60 kg liveweight, and receiving rations containing 0, 2 or 10% expeller-extracted rapeseed meal, with rapeseed meal replacing soybean meal on an isonitrogenous basis. With the younger pigs, the highest level of rapeseed meal did depress digestibility to a non-significant degree, however. The 10% level of this same rapeseed meal significantly depressed apparent digestibility of dry matter, energy and nitrogen in rats. Retention of digestible nitrogen in pigs and rats was unaltered by the rations fed. For example, 7 kg pigs receiving 10% rapeseed meal (70% of the supplemental protein) retained 42% of the nitrogen absorbed as compared to 41% retained for those receiving the basal diet with rapeseed meal.

Manns and Bowland (24) observed a reduction in digestibility of dry matter by 34 kg pigs receiving 100% rapeseed meal in substitution for isonitrogenous amounts of soybean meal but no other significant changes in digestibility when 25 to 100% rapeseed meal was substituted for soybean meal. When rapeseed meal was substituted at the 100% level there was a trend toward reduced digestibility of dry matter, energy and nitrogen with finishing pigs and with gilts during gestation and lactation. A supplement of 0.2% lysine added to the ration containing the highest level of rapeseed meal improved dry matter, energy and nitrogen digestibilities for pigs at 34 kg liveweight and during gestation and lactation. The cause of reduced digestibility and retention in some cases when rapeseed meal was fed may be related to thyroid activity (25), but may also be related to levels and availability of amino acids in the meal as evidenced by the improved digestibility when supplemental lysine was fed.

The data (24) suggest that reduced gain and poorer efficiency of feed utilization may be partly associated with lowered digestibility and reten-

tion of energy and nutrients. Fevrier (16) observed, however, that high-temperature treatment of rapeseed meal lowered digestibility of the meal but that the rate of gain of swine fed this meal was improved over those fed meal processed at a lower temperature. He suggests that the harmful factors in the meal that are removed by heat treatment have a greater effect on performance than the reduced digestibility resulting from the excessive heat treatment.

In studies with solvent-extracted rapeseed meal of *B. campestris* origin, and free of active myrosinase, Bell (6) obtained no reduction in digestibility of energy and protein when the meal was fed to growing and finishing pigs. When ground rapeseed screenings were added as a source of myrosinase there was evidence of a depression in digestibility coefficients for energy and protein. Therefore the presence of the enzyme, myrosinase, may be implicated in digestibility depression.

Goitrogens and Other Factors in Rapeseed Meal

As outlined in Chapter 4, rapeseed meal contains goitrogenic principles which may be modified by processing procedures. It is also shown that rapeseed meal may contain other potentially toxic factors. In the reviews by Altschul (1) and Bell (4) it is suggested that the only satisfactory method of counteracting the total effect of the factor(s) is to limit the use of the meal.

Hypertrophy of the thyroid has been widely noted when rapeseed meal is fed to pigs (16, 20, 25, 28, 32). Iodide and iodinated casein have been partially effective against the rapeseed goitrogens. For example, Nordfeldt et al. (28) found that 0.5 g iodinated casein per 100 kg body weight when fed to pigs receiving rapeseed meal did not affect growth, but reduced thyroid enlargement. Intensive steam treatment of rapeseed meal has also improved its feeding value for pigs (16).

Fevrier (16) observed that the rat behaved similarly to swine in relation to thyroid enlargement as well as general performance and that rats might be useful as test animals. In studies at the University of Alberta (20, 21, 23, 24, 25) it was also found that the rat and the pig generally responded very similarly to feeding of rapeseed meal at various physiological stages in the life cycle.

Hussar and Bowland (20) conducted detailed histological examination of the thyroid glands from market pigs at 89 kg liveweight. In pigs receiving 0, 2 or 10% rapeseed meal from 6 kg liveweight to slaughter, the thyroid glands weighed 5.9, 6.6 and 17.3 g respectively. At the 2% level there was evidence of some increase in cellular components and limited glandular hypertrophy, while at the 10% level there was a marked increase in cellular components and glandular hypertrophy evident. Manns et al. (25) observed moderate hypertrophy of thyroid glands of market pigs that received rapeseed meal. Based on concurrent studies with rats and

previous observations of Kennedy and Purves (22) they suggest that pigs adapt to the goitrogen in rapeseed meal so that there is a decrease in thyroid hypertrophy relative to body weight after an initial period of thyroid response (*see* Chapter 4).

A change in the size of other organs has also been reported when rapeseed meal is fed. For example, enlarged livers and kidneys in market pigs were observed by Nordfeldt et al. (28) and Seale (32) and enlarged livers in sows and market pigs were noted by Bowland et al. (13).

Manns et al. (25) found that rate of gain and efficiency of feed utilization in pigs fed rapeseed meal appeared to be related to the degree of thyroid malfunction. On the other hand there is not always a definite correlation between thyroid enlargement and growth depression when rapeseed meal is fed (28).

The formation of mustard oils in rapeseed meal has been suggested as a digestive tract irritant (18, 19, 26). Frölich and Haring (18, 19) reported that digestive tract disturbances could be alleviated by feeding charcoal. Seale (32) noted no symptoms of digestive disturbances in his study with rapeseed meal. Although not specifically studied by other research workers, the results of most experiments do not suggest digestive disturbances. It is of interest, however, that Anderson and Hurwitz (2) observed that in *in vitro* studies allyl isothiocyanate was effective against *Ascaris lumbricoides* (roundworm) of swine.

Vitamin A storage per g of liver and in the total liver was increased for sows receiving rapeseed meal as a replacement for soybean meal in the ration whether or not the rapeseed ration was supplemented with 0.2% L-lysine (14). This increased storage may indicate a reduced metabolic utilization of vitamin A as suggested by Bamji and Sundaresan (3) and others. Pigs killed at 90 kg liveweight failed to show a similar increased liver storage of vitamin A when rapeseed meal was fed.

Rapeseed Oil

(*See* Chapter 1 for further discussion)

Supplemental fats or oils are being added to pig rations as a method of increasing energy levels of the ration, particularly for young pigs. A series of Finnish studies (29, 30, 31) have compared rapeseed oil with soybean oil as an addition to swine rations. Digestibility of both oils was found to be approximately 100 percent (29). This agrees with studies by Franke (17) in Germany in which a digestibility coefficient of 99.2% was obtained for rapeseed oil in swine rations. The Finnish work reported a reduced rate of gain for pigs fed rapeseed oil as compared to soybean oil with both oils added to supply 28% of the caloric intake in the feed of weanling pigs. Both oils resulted in a mild interstitial myocarditis and gastritis, which was not evident in pigs fed a basal diet. With older pigs fed 150 g oil per kg meal there was little difference in rate of growth when pigs were fed at

a restricted level, but when fed to appetite those fed soybean oil ate more and gained faster than those fed rapeseed oil. Water consumption was greater for the pigs fed rapeseed oil. Carcass measurements did not differ significantly between treatments.

General Recommendations

As discussed in Chapters 1 to 4 and briefly outlined in the Introduction to this chapter, the solvent-extracted rapeseed meal at present available in Canada is a superior meal to that previously available in Canada and elsewhere. Although swine are probably the least tolerant to rapeseed meal of any of the domestic species (1, 16) this meal may be used in the formulation of rations for most classes of pigs.

For young pigs during the starting period to 25 kg in weight, 4% of the total ration may be composed of solvent-extracted rapeseed meal. As the meal may lack in palatability, it is advisable to use it cautiously in creep-feed rations. For market pigs from 25 to 90 kg liveweight, the meal may be used as up to 10% of the total ration. Feed intake and rate of gain may be reduced slightly at this level of feeding but efficiency of feed utilization is not affected. The limited evidence available on the use of rapeseed meal for pre-gestation, gestation and lactation suggests that as a protein source, for swine breeding stock, particularly females during gestation and lactation, rapeseed meal is unsuitable at a level above 3% of the total ration. Breeding boars appear to be unaffected by a level of rapeseed meal as high as that recommended for market pigs.

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CHAPTER 7. FEEDING VALUE OF RAPESEED MEAL FOR POULTRY

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Introduction

Of interest in relation to recent research work on rapeseed meal are the extensive studies by Frölich (15, 16, 17) in Sweden on solvent-processed rapeseed meal, who reported that up to 10% rapeseed meal may be used in the diet of growing chickens with only moderate growth retarding effect. Thyroid enlargement, however, was noted even when as little as 5% rapeseed meal was included in the chicks' diet. Frölich was able to reduce the thyroid enlarging effects of rapeseed meal by extracting the meals with water or 70% alcohol. He was also able to counteract the thyroid enlargement by administration of DL-thyroxine but was unable to alleviate the condition by the inclusion of 10 ppm of supplementary iodine in the diet.

Starting and Growing Chickens

Much of the rapeseed meal produced in America prior to 1958 was inferior to soybean meal as a protein feedstuff for chicks. In this regard, up to 25% slower growth and 10% lower feed efficiency were frequently obtained (11, 14, 23, 24, 29, 34, 36) from chick starter rations containing rapeseed meal as compared to rations containing other protein feedstuffs as the source of supplementary protein. Even when only part of the supplementary protein in the ration was supplied by these expeller-processed rapeseed meals, decreased growth rate and depressed feed efficiency occurred (8, 11) (*see* Table 7.1).

It was soon learned (11) (*see* Table 7.2) that the use of high temperatures during the cooking and conditioning of rapeseed in the expeller process resulted in meals of inferior feeding value; the low feeding value of over-heated meals was associated with a greater than 25% reduction in the lysine content of the protein of such meals as compared to meals subjected to less drastic heat treatment. On the other hand, low processing temperatures were shown to leave more oil in the meals, an undesirable effect from the processor's point of view, since he is primarily interested in maximum oil yield. In further studies it was found (12) that in the expeller process only sufficient heat should be applied in cooking and conditioning

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Table 7.1 Effect of expeller-processed rapeseed meal on chick growth and feed efficiency

	Ration number							
	1	2	3	4	5	6	7	8
Starter basal,* %	86	86	86	86	86	86	86	86
Ground wheat, %	4.0	4.0	4.0	4.0	4.0	3.1	2.2	0.4
Soybean meal (44% protein), %	10.0	7.5	5.0		10.0	8.4	6.8	3.6
Argentine rapeseed meal,† %		2.5	5.0	10.0				
Polish rapeseed meal,‡ %						2.5	5.0	10.0
Protein (N × 6.25) in ration, %	21.5	21.5	21.1	21.2	21.6	21.4	21.6	21.7
Number of chicks§	61	62	62	62	62	61	61	62
Average weight, 8 weeks, g	1,034	1,009	993	910	1,024	1,042	1,051	979
Feed/g gain, 8 weeks, g	2.6	2.7	2.8	2.9	2.6	2.6	2.6	2.7

*The starter basal contained the following ingredients: ground wheat, 42.125; ground corn, 20.0; ground oats, 5.0; dehydrated alfalfa meal, 3.0; meat meal, 4.0; herring meal, 3.0; soybean meal, 5.0; limestone, 1.5; bone meal, 1.0; iodized salt, 0.25; fish oil (2250A, 300D), 0.125; insoluble grit, 1.0. In addition, the starter basal was supplemented with 0.23 kg manganese sulphate, 3 g riboflavin, 9 g calcium pantothenate, 15 g niacin, 0.45 kg dry D_3 (1,650,000 ICU/kg), 0.91 kg Merck vitamin B_{12} and antibiotic feed supplement, 1.82 kg Merck 25% choline chloride premix per ton of finished starter.

†Meal produced by the expeller process from *Brassica napus* rapeseed, N × 6.25=43.3.

‡Meal produced by the expeller process from *Brassica campestris* rapeseed, N × 6.25=33.9.

§Single Comb White Leghorn, mixed sexes.

to permit reduction of the oil content of the meal to about 6% if damage to protein quality as measured by lysine content was to be avoided. That the lysine content of expeller-processed rapeseed meal can be limiting in so far as its use in chick starter rations is concerned has been demonstrated by Kratzer et al. (24) and Klain et al. (23) and confirmed in our laboratories (unpublished data). In these 1955 chick growth trials, the chicks receiving rations supplemented with rapeseed meal weighed 222 g while those receiving rapeseed meal plus 0.5% L-lysine weighed 352 g at 4 weeks of age. (*See* Chapters 2 and 3 for further discussion of processing and meal composition.)

Processors in Canada have converted from expeller processing to pre-press-solvent or solvent methods of processing. This change has occurred because processors realize that maximum oil yield may be obtained by solvent methods without risk of heat damage to the protein of the by-product. However, evidence has been obtained in our laboratory (8) that,

Table 7. 2. Effect of processing temperatures on the nutritive value and chemical composition of expeller-processed rapeseed meal

Ration No.	Treatment*	No. of chicks	Body weight 4 wk g	Thyroid size, mg per 100 g body wt†	Protein in meal %	Fat in meal %	Lysine in protein of meal %
1	Soybean meal Solvent processed	30	381.5	9.0	44.2	0.4	6.11
2	Rapeseed meal Cooker‡ 121 C (250 F) Conditioner‡ 127 C (260 F)	30	274.5	25.1	36.4	5.9	4.12
3	Rapeseed meal Cooker‡ 112C (234 F) Conditioner‡ 127 C (260 F)	30	324.0	19.5	35.0	6.6	4.86
4	Rapeseed meal Cooker‡ 104 C (220 F) Conditioner‡ 116 C (240 F)	30	365.0	20.0	34.8	7.3	5.69
	Average run of rapeseed				31.8	35.0	6.42

*Meals incorporated as sole source of supplementary protein in a 22% protein chick starter.

†Average of six male and six female chicks.

‡Crushed seed took approximately 30 minutes to pass through the cooker and 5 minutes to pass through the conditioner.

from the point of view of chick growth promotion alone, low-temperature expeller-processed rapeseed meal can give just as satisfactory results as prepress-solvent meal and both of these types of meals may be expected to approach solvent-processed soybean meal in growth promotion (*see* Table 7.3). In spite of this fact, the switch to prepress solvent or solvent processing of rapeseed in Canada has been complete. During 1958 to 1961 ten prepress-solvent and five solvent-processed meals were tested in our laboratory in a chick starter at the 15% level, replacing an equivalent amount of protein from soybean meal, no attempt being made to compensate for the lower energy content of the rapeseed-containing rations. On the average, the chicks fed prepress-solvent and solvent meals grew 94 and 95.4% respectively as fast as chicks fed the soybean meal control ration.

In more recent studies in our laboratory, 14 samples of commercial prepress-solvent and solvent-processed rapeseed meals were included in a 23% protein broiler ration at the 15% level as a replacement for part of the soybean meal in the ration. The rations were kept isonitrogenous and isocaloric. Energy levels were maintained constant by including supplementary fat in the diets containing rapeseed meal. The fiber content of the soybean control diet was 3.8% while that of the rapeseed meal rations ranged from 5 to 5.5 percent. Growth of chicks and feed conversion were equally as good on the rations containing rapeseed meal as on those contain-

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Table 7.3 Composition of and chick growth obtained from rapeseed meals compared to soybean meal

Meal No.	Description	Year meal obtained	Protein in meal %	Lysine in protein of meal %	Average weight (g) of chicks at 4 weeks of age*				
					Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
1	Solvent-processed soybean meal		50.1††	6.11	367	308	337	308	448
2	High-temperature expeller rapeseed meal† (RSM)	1957	36.4	4.12	226				
3	Medium-temperature expeller RSM†	1957	35.0	4.86	282				
4	Low-temperature expeller RSM†	1957	34.8	5.69	375				
5	Prepress-solvent RSM	1958	37.8	5.10	339	280			
6	Prepress-expeller RSM‡	1958	36.4	5.53	363	297			
7	Prepress-solvent RSM‡	1958	38.5	5.50	347	300			
8	Prepress-solvent RSM§	1959	37.6	5.27			323		
9	Prepress-solvent RSM**	1959	40.2	4.84			317	307	
10	Prepress-solvent RSM	1961	36.2	5.21					427

*In the soybean controls, 50% protein solvent soybean meal was the only source of supplementary protein. In the rapeseed meal rations, all of the soybean meal was replaced on a protein equivalent basis with rapeseed meal, the percentage of wheat being reduced in these rations to take care of the higher percentage of rapeseed meal required to replace the soybean meal. The following numbers of chicks were involved per treatment in the various experiments: Experiment 1, 16 male chicks; Experiment 2, 20 male and 20 female chicks; Experiment 3, quadruplicate lots of 20 chicks of mixed sexes; Experiment 4, duplicate lots of 25 male chicks; Experiment 5, quadruplicate lots of 12 chicks of mixed sexes.

†Prepared from similar raw material.

‡Prepared from similar raw material.

§Prepared from Polish-type (*Brassica napus*) rapeseed.

**Prepared from Argentine-type (*Brassica campestris*) rapeseed.

††This soybean meal was used in Experiment 1 and Experiment 2.

ing soybean meal (*see* Table 7.4). These results stress the need for adjusting the energy levels of rations containing rapeseed in order to compensate for the lower metabolizable energy content of rapeseed meal as compared to soybean meal (32, 33). Thyroid-to-body-weight ratios were higher in the chicks fed rapeseed meal. The significance of the latter will be discussed in this chapter.

The fact that "top quality" expeller-processed and prepress-solvent and solvent-processed rapeseed meal approach or equal soybean meal in growth promotion is not surprising since the essential amino acid content of the protein of rapeseed and of good-quality rapeseed meal compares favorably with that of the protein of soybean and of soybean meal respectively

Table 7.4. Relative feeding value of prepress-solvent and solvent rapeseed meals as compared to soybean meal

Ration No.	Rapeseed meal No.	Rapeseed meal Source*	Treatment	Protein in meal %	Relative growth† %	Feed per g gain† g	Thyroid size, mg per 100 g body wt‡
			Experiment 1, 1962 Crop Rapeseed				
1			Soybean meal control	45.2	100.0	2.20	10.4
2	1	WCSP	15% RSM	36.7	106.4	2.15	15.8
3	2	WCSP	15% RSM	36.5	104.9	2.17	10.9
4	3	WCSP	15% RSM	36.5	106.2	2.19	15.9
5	4	WCSP	15% RSM	37.2	109.5	2.22	11.4
6	5	SWP	15% RSM	37.5	103.4	2.22	13.8
			Experiment 2, 1962 Crop Rapeseed				
7			Soybean meal control	45.6	100.0	2.30	10.2
8	6	WCSP	15% RSM	36.4	100.4	2.18	16.7
9	7	CVO	15% RSM	38.9	102.2	2.10	17.8
10	8	SWP	15% RSM	39.5	105.2	2.05	17.8
11	9	SWP	15% RSM	40.0	105.6	2.06	17.1
			Experiment 3, 1963 Crop Rapeseed				
12			Soybean meal control	44.8	100.0	2.46	6.4
13	10	SWP	15% RSM	39.8	98.7	2.58	10.9
14	11	SWP	15% RSM	38.7	99.2	2.50	12.2
15	12	SWP	15% RSM	39.2	96.4	2.60	11.6
16	13	WCSP	15% RSM	37.1	99.2	2.47	12.7
17	14	AVOP	15% RSM	38.3	97.7	2.55	16.0
	Averages—Soybean meal			45.2	100.0	2.32	9.1
	Rapeseed meal			38.2	102.5	2.28	14.3

*AVOP, Agra Vegetable Oils Products Ltd., Nipawin, Saskatchewan.
CVO, Co-op Vegetable Oils Ltd., Altona, Manitoba.
SWP, Saskatchewan Wheat Pool, Saskatoon, Saskatchewan.
WCSP, Western Canada Seed Processors Ltd., Lethbridge, Alberta.

†Duplicate lots of 20 female chicks on each treatment in Experiment 1; 16 female chicks per treatment in Experiment 2; and duplicate lots of 18 mixed chicks per treatment in Experiment 3.

‡Average of six female chicks in Experiments 1 and 2; average of four male and four female chicks in Experiment 3.

(10, 25, 26) (*see* Table 7.5). From the point of view of the two most limiting amino acids in chick starters based on vegetable protein supplements, i.e. lysine and methionine, rations supplemented with rapeseed meal are likely to be similar or higher in methionine and somewhat lower in lysine content than those supplemented with soybean meal. This may also be deduced from the analytical data of Klain et al. (23) and De Vuyst et al. (13).

Table 7.5. Percentages of some amino acids in the protein of rapeseed, rapeseed meal, soybeans and soybean meal as determined by microbiological assay

Amino acid	Rape		Soybean	
	Seed*	Meal†	Seed‡	Meal§
Arginine	5.8	5.8	7.7	7.5
Histidine	2.2	2.9	2.3	2.5
Isoleucine	3.9	4.1	5.3	5.5
Leucine	6.4	7.2	7.9	7.7
Lysine	5.4	5.5	6.6	6.2
Methionine	1.3	1.3**	1.4	1.4
Phenylalanine	3.6	4.1	5.1	4.9
Threonine	4.0	4.4	3.9	4.0
Valine	4.3	5.4	5.3	5.4

*Average of four varieties grown at three different locations in Alberta in 1955 (10).

†Average of 15 samples of prepress-solvent and solvent-processed rapeseed meal processed during 1958-61 (D.R. Clandinin, unpublished data).

‡Average of 20 strains of soybeans (25).

§Lyman et al. (26).

**When these 15 samples of rapeseed meal were analyzed for amino acid content using a Beckman/Spinco amino acid analyzer, an average value for methionine of 1.9% of the protein was obtained (D.R. Clandinin, unpublished data, 1962-63).

Laying and Breeding Chickens

O'Neil (28) reported on three experiments designed to assess the suitability of expeller-processed rapeseed meal as a replacement for soybean meal in laying rations for chickens. In one experiment, varying amounts of rapeseed meal replaced soybean meal on a protein equivalent basis in the diet. In addition to the vegetable protein supplement, the rations contained 2% meat meal and 1% fishmeal as sources of supplementary protein. No significant differences between treatments for either percentage production or amount of feed required to produce a dozen eggs were observed. In a second experiment, in addition to replacing soybean meal on a protein equivalent basis, the levels of calcium and phosphorus were adjusted so that the diets had the same quantity of these minerals. Again egg production

and feed per dozen eggs were found to be similar for both treatments. In the third experiment rapeseed meal was used to replace all of the soybean meal when animal protein was fed at either the 3 or 1½% level. No significant differences between treatments in the productive traits studied or in hatchability of eggs produced were noted. In our laboratory (unpublished data, 1955-56) groups of 30 White Leghorn pullets in batteries laid at similar rates over a 24-week period when fed rations containing 0, 3, 6 and 9% expeller-processed rapeseed meal replacing soybean meal. In addition to the vegetable protein supplement(s) the rations contained 0.5% fishmeal.

Starting and Growing Turkeys

Blakely and Anderson (3, 4) demonstrated that the inclusion of rapeseed meal, presumably expeller-processed meal, in a turkey starting ration as a replacement for meat meal reduced growth rate. However, the fact that these workers observed white barring in the groups fed rapeseed meal suggests that the meal used was low in lysine content, which may account for the reduced growth noted. In a later experiment MacGregor and Blakely (27) again found that the inclusion of 10% of expeller-processed rapeseed meal as a replacement for soybean meal in rations fed turkeys from day-old to 24 weeks depressed rate of growth significantly. It would appear that more research should be undertaken to determine the effects of feeding high-quality solvent-processed rapeseed meal to starting and growing turkeys.

The use of whole rapeseed as an energy source in finishing rations for turkeys has been studied by Blakely and MacGregor (5). The control diet contained 10% of stabilized tallow while the diet containing whole rapeseed contained sufficient whole rapeseed to supply 10% oil. The protein content of the latter diet was adjusted by removing part of the soybean meal and ground wheat. At the end of a 4-week feeding period no differences were noted in the body weight of the birds on the two treatments, however, a highly significant improvement in carcass score was noted in the turkeys fed whole rapeseed.

Laying and Breeding Turkeys

In studies on the use of expeller and prepress-solvent-processed rapeseed meal in turkey breeding rations as a replacement for soybean meal, MacGregor and Blakely (27) found that 10% expeller or prepress-solvent-processed meal could be used without adverse effects on egg production or feed efficiency. In so far as hatchability was concerned, there were indications that expeller-processed rapeseed meal did not support quite as high hatchability as soybean meal (*see* Table 7.6). These workers suggested that the expeller-processed meal may have been slightly low in lysine content and that this may have accounted for the difference in the results obtained from the two types of meals. In a two-year study in which, in each year, duplicate

Table 7.6. Effect of prepress-solvent rapeseed meal as a replacement for soybean meal in a turkey breeding ration*

	Soybean meal control	10% prepress-solvent-processed rapeseed meal
Birds per ration	80	80
Broodiness, cases	173	180
Production, hen-day, %	48.0	45.0
Average egg weight, g	91.1	90.4
Change in body weight, kg	+.19	+.13
Feed per dozen eggs, kg	6.3	6.4
Hatch of fertile eggs, %	65.0	63.0

*Data from MacGregor and Blakely (27). None of the differences between treatments were significant ($P < 0.10$).

groups of 72 Broad Breasted turkeys were fed a breeding ration containing soybean meal as the main supplementary source of protein and one in which solvent-processed rapeseed meal replaced most of the soybean meal in the ration, Robblee and Clandinin (unpublished data, 1962-63) noted no adverse effects on egg production, feed conversion or percentage hatch as a result of the substitution (*see* Table 7.7 for 1963 data).

Table 7.7. Effect of solvent-processed rapeseed meal as a replacement for soybean meal in a turkey breeding ration*

	Soybean meal control	10% solvent rapeseed meal
Birds per ration	144	144
Mortality, no.	5	6
Broodiness, no.	226	204
Production, hen-housed, %	55.5	55.5
Feed per dozen eggs, kg	6.8	7.2
Fertility, %	82.7	79.4
Hatch of fertile eggs, %	66.6	72.0
Hatch of all eggs, %	55.0	57.1

*Experiment covered period January 1 to April 30, 1963 (unpublished data of A.R. Robblee and D.R. Clandinin).

Goitrogenic Effects of Rapeseed Meal in Poultry

Workers in New Zealand (18, 19, 20, 21, 22, 30) have studied extensively the effects on the thyroid and pituitary glands of feeding rapeseed to rats. Details of their work are reviewed in Chapter 4 of this publication; however, reference here to their work does not seem out of place since it ties in closely with work that has been done with poultry. Briefly, these workers found that the feeding of rapeseed to rats interferes with the power of the thyroid to synthesize thyroxine. The resultant fall in the level of thyroxine in the circulation induces the pituitary to secrete excessive amounts of thyrotropin which acts on the thyroid causing hypertrophy and hyperplasia. By the end of the third week on rations containing rapeseed, thyroid changes are at a maximum. After this, growth of the gland parallels that of the rat. The thyroid apparently reaches physiological equilibrium at an increased thyroid-to-body-weight ratio.

Numerous workers (3, 11, 14, 17, 23, 34, 36) have reported thyroid enlargement as a result of feeding rapeseed meal to poultry. In general, meal produced from Argentine-type seed (*Brassica napus*) has been shown (11, 23) to cause a greater degree of enlargement than meal produced from Polish-type seed (*Brassica campestris*). This is attributed to the higher (-)-5-vinyl-2-oxazolidinethione content of rapeseed meal produced from *B. napus* seed as compared to that produced from *B. campestris* seed (10, 35). (Astwood et al. (1, 2) and Carroll (6) isolated goitrin from rapeseed and identified it as L-5-vinyl-2-thiooxazolidone, which has more recently been named (-)-5-vinyl-2-oxazolidinethione, *see* Chapter 4.) It has also been observed that prepress-solvent and solvent-processed rapeseed meals are slightly less goitrogenic to poultry than expeller-processed meals ((11) and Table 7.4). This difference is no doubt mainly due to the fact that a higher percentage of the rapeseed grown throughout Canada in recent years has been of the *B. campestris* type.

Efforts to counteract the thyroid enlargement of chickens fed rapeseed meal by feeding supplementary iodine have been only partially successful (9, 14, 23, 24). On the other hand, feeding Protamone or injecting L-thyroxine has resulted in a reduction of the thyroid-to-body-weight ratio of rapeseed meal fed poultry (4, 9, 23, 24).

Clandinin and Bayly (9) studied the histology of the thyroid glands of chickens and laying hens that had been fed rapeseed meal with and without stabilized iodine for a month or more. They found that an increase in the number and size of the epithelial cells in the glands accounted for the increase in thyroid size of growing chickens fed rapeseed meal. When stabilized iodine was added to the diet of rapeseed meal fed chicks, the glandular enlargement was found to be caused by increased follicle size and increased colloid storage; however, the cells appeared normal in size

and shape. In the case of laying hens fed rapeseed meal, initially, the glands exhibited enlargement as a result of an increase in number of follicles, the follicles being well defined. As time of treatment progressed, the follicles toward the central portion of the glands became distorted and completely filled with cells and the amount of colloid was greatly reduced. When stabilized iodine was added to the ration of rapeseed meal fed layers, the glands were enlarged. The glandular enlargement in this instance was found to be caused by increased follicle size and increased storage of colloid. As in the case of chicks, iodine supplementation tended to bring about a more normal stucture in the glands. It would appear from this work that rapeseed meal in the diet of chickens results in histological changes in the thyroid glands and that provision of adequate amounts of iodine in the diet tends to correct the abnormal histological picture.

In an extensive series of experiments designed to study the effects of rapeseed meal, progoitrin and goitrin on the uptake and release of radio-iodine from the thyroid glands, Clandinin, Caballero and Bayly (unpublished data, 1961-64) found that the initial effect of including these supplements in the diet of the chick is that of decreasing the uptake of radio-iodine by the thyroid glands and increasing the rate of release of radio-iodine from the glands. It is not known at this time whether the iodine released from the glands is in free or bound form. It was also found that after chicks have received any one of these supplements for several weeks, the uptake of radio-iodine by the hypertrophied glands is greatly increased. The daily secretion of radio-iodine from the latter glands, however, was found to be normal. These results support the conclusion that chicks fed rapeseed meal, progoitrin or goitrin, like rats fed rapeseed (18, 19, 20, 21, 22, 30), eventually reach physiological equilibrium at increased thyroid-to-body-weight ratios. Results of this study also showed that goitrin ((-)-5-vinyl-2-oxazolidinethione) at relatively high levels in the diet depresses chick growth and that myrosinase from rapeseed does not have to be supplied in the diet for progoitrin to produce its anti-thyroid effects in the chick. Progoitrin is converted to goitrin by the enzyme myrosinase which is present in rapeseed. The latter observation is in agreement with the finding in our laboratory that expeller-processed rapeseed meals are goitrogenic yet they show no myrosinase activity.

Schwarze (31) has shown that the bitter taste of ground rapeseed is due to sinapin. Clandinin (7) has demonstrated that when sinapin, isolated from rapeseed meal as the thiocyanate and purified as the bisulfate, was added to a soybean-meal-type chick starter at a level which would supply an amount of sinapin comparable to that present in a starter ration in which the main source of supplementary protein was rapeseed meal, normal growth rate was obtained. Hence, the bitter substance in rapeseed meal cannot be implicated in the chick growth depressions that have been obtained from some commercial rapeseed meals.

Summary and General Recommendations

Many expeller-processed rapeseed meals have been found to support a low rate of growth in chicks and poults. Low-temperature expeller-processed rapeseed meals have been shown to approach or equal soybean meal for chick growth promotion. In general, where slow growth rate has been obtained from expeller-processed rapeseed meal, it has been associated with low lysine content of the meals resulting from over-heating during processing. Prepress-solvent and solvent-processed rapeseed meals, which, of course, have not been subjected to excessive heat treatment in processing, have, in contrast, been found equivalent to soybean meal for chick growth promotion and feed conversion when energy-protein relationships are maintained constant. This seems quite understandable since the amino acid distribution in rapeseed protein has been shown to be comparable to that of soybean protein. On the basis of the growth studies reviewed there does not appear to be any reason why 10 to 15% low-temperature expeller, prepress-solvent or solvent-processed rapeseed meal should not be used in chick starter rations.

In so far as laying and breeding chickens and turkeys are concerned, 10% prepress-solvent or solvent-processed rapeseed meal has been shown to yield just as satisfactory production, feed conversion, fertility and hatchability as corresponding amounts of protein from soybean meal.

Efforts to counteract thyroid enlargement caused by rapeseed meal by feeding supplementary amounts of stabilized iodine, have only been partially successful. Enlargement, however, has been suppressed by feeding Protamone or by L-thyroxine injection.

It would appear that the initial effects on the thyroid glands caused by feeding rapeseed meal to poultry include decreasing the uptake of iodine by the glands and increasing the release of iodine from the glands. After poultry have been fed rapeseed for 3 or 4 weeks, uptake of iodine by the hypertrophied thyroid glands is greatly increased while secretion rate from the glands appears normal. It would seem, therefore, that after poultry have received rapeseed meal for a short period of time a physiological equilibrium is reached at an increased thyroid-to-body-weight ratio.

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CHAPTER 8. STATUS OF RAPESEED MEAL AS A PROTEIN SUPPLEMENT

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In the foregoing chapters an attempt has been made to provide an up-to-date review of authentic information on rapeseed meal that may be of interest and value to users and potential users of the product. It has been the opinion of many research workers in Canada that the rapeseed meals being produced today are much superior to those produced a few years ago. It has also been their belief that the modern meals are not being used in feed formulation to as great an extent as they might be when factors such as quality, availability and price are taken into consideration. It is hoped that this monograph, which includes results of recent research on rapeseed meal, may serve to counteract prejudices against rapeseed meal as a protein supplement arising from some adverse results obtained with meals produced 10 or 15 years ago.

Rapeseed is a crop well adapted to Canadian conditions. It matures in a relatively short growing season; it provides an alternative to cereal crops in a cropping program; it is a good source of vegetable oil, and, as a byproduct of oil extraction, it provides a high-protein meal suitable for livestock feeding.

In Canada, acreage devoted to rapeseed production has increased rapidly until supply of the seed has greatly exceeded domestic demand. As a consequence, in recent years Canada has exported more rapeseed than all other countries in the world combined. The product is usually exported as the seed; it is crushed and extracted by the importing country.

For the most part, two types of rapeseed are being produced in Canada, *B. napus* (Argentine rape) and *B. campestris* (Polish rape). Of the two species, *B. napus* has a greater potential yield of seed and oil than *B. campestris* but varieties of the latter species are usually preferred in Canada because they mature approximately 2 weeks earlier.

Breeding programs have been undertaken in Canada to produce new varieties of rapeseed. Factors being considered in developing new varieties include yield of seed and oil, composition of the oil and level of thioglucosides in the seed. Considerable progress has been made; varieties have been selected with greater yield potential, differing oil composition, and lower levels of the thioglucosides. The future holds promise that varieties will be produced that are vastly superior to those now available.

Processing methods used for the extraction of oil from rapeseed have undergone considerable change over the years. Ten or 15 years ago most of the meal was produced by the expeller process; today, meals are produced in Canada by either the prepress-solvent or by the solvent process. As a result the meals currently being produced differ from those that were available previously. Modern meals are subjected to less heat during processing and the amount of oil left in the meal is greatly reduced as compared to expeller meals. Because of the reduction in the amount of heat used in processing, the meals are of much better quality than those produced a few years ago.

Modern varieties of rapeseed yield approximately 40% of oil and 50% of meal, with the remainder being moisture. Examination of the analyses of the proximate principles of the meals indicates that, in general, they are comparable to other plant protein meals. Protein levels vary depending upon variety, year and soil type with values ranging from 32 to 44%; fat content depends on the extraction procedures employed but usually ranges from 1 to 2% in prepress-solvent or solvent meals; crude fiber levels in the meals are higher than in most other plant protein meals; and levels of nitrogen-free extract and ash are similar to those found in other oil seed meals.

When one examines the essential amino acid composition of modern rapeseed meals it is obvious that the protein that is present is suitable for livestock feeding. The balance or array of amino acids is superior to that seen in many other plant protein meals and compares quite favorably with soybean meal. It would therefore appear that the potential of rapeseed meal as a protein supplement has often been overlooked. Failure to recognize this potential may have stemmed from earlier reports of experimental work conducted with expeller meals in which damage to the protein had occurred during processing. The use of high temperatures during processing results in a reduction in the levels of some of the essential amino acids in the meals produced. For instance, with meals produced by the expeller process, values for the amount of lysine present generally ranged from 3.5 to 4.4% of the protein as compared to an average of 5.5% of lysine found in the protein of a number of solvent meals for which values have been reported. Since lysine is often the most limiting of the essential amino acids in practical feeds for monogastric animals, estimations of the value of the protein in rapeseed meal should recognize the importance that lysine level may have on the biological value of the protein. If lysine levels are used as a basis of comparison the protein of solvent-processed rapeseed meals would have approximately 90% as much value as the protein of soybean meal.

In the preceding chapters several references have been made to the presence of thioglucosides in rapeseed meal and to the possible adverse effects that their hydrolytic products, isothiocyanates and oxazolidinethione, may exert on thyroid size, reproduction, growth rate and livability in some

species of animals. There is no doubt that problems arising because of the effects of these compounds on the animal have been responsible for much of the bad publicity that rapeseed meal has received in the past. The situation is complicated by many factors. Levels of isothiocyanates and oxazolidinethione in rapeseed meal may vary depending upon variety, growing conditions, levels of available sulfate in the soil, and processing methods used in producing the meal. In addition effects noted in experimental animals may be influenced by age, sex and species. Because of the many variables that may be involved it is sometimes difficult or impossible to ascribe the effects noted to a particular factor. In so far as the thioglucoside levels and their effects on livestock and poultry are concerned, one might optimistically predict that the plant breeder will, in time, produce varieties containing very low levels of these substances. In the meantime, it is apparent that varieties of Polish rapeseed contain lower levels of glucosides, are less goitrogenic and, therefore, are of superior quality to varieties of Argentine rapeseed in livestock feeding.

In order to obtain the greatest measure of satisfaction from the use of rapeseed meal, some attention should be given to the differences that do exist between species of animals in their response to the inclusion of rapeseed meal in the ration. This varies from little or no effect with ruminants, slight effects with growing swine and poultry, to serious impairment of reproductive ability with breeding swine. The occurrence of variability of this sort serves to emphasize that research results obtained with one species may not necessarily be applicable to another. It also indicates that rapeseed meal should be used within the limits that have been shown to be suitable by appropriate experimentation with the species involved.

The use of rapeseed meal in rations for cattle and sheep has resulted in little real difficulty; nevertheless, the product has been regarded with some disfavor by producers. Resistance against the use of the meal has arisen because of an apparent reluctance on the part of ruminant animals to consume rations containing rapeseed meal when such feeds are first fed. The lack of acceptability only lasts for the first few days of the feeding period, after which palatability no longer appears to be a problem. Because lack of palatability may be a problem initially, if rapeseed meal is to be incorporated into a ration at high levels, it is generally recommended that the meal be introduced gradually into the feeding program.

The results of numerous experiments with cattle and sheep indicate that no serious problems should be encountered through the use of rapeseed meal in practical rations. Ruminant animals do not develop enlarged thyroid glands and no adverse effects on the rate of gain or reproduction have been noted when solvent-extracted rapeseed meal was fed at high levels. In addition, neither yield nor flavor of the milk was affected by inclusion of rapeseed meal in the ration. These results have led to a general recommendation that solvent-extracted rapeseed meals, similar to those

produced in Canada, can be considered to be equivalent to other plant protein meals when used in rations for ruminants at levels up to 10% of the total dry matter of the ration.

Rapeseed meal is also a satisfactory protein supplement for swine, but it should be used with more caution in rations for this species than for ruminants. There is some evidence that swine are less tolerant than other farm livestock to rations containing high levels of rapeseed meal. When high levels of the meal are fed the thyroid gland may be enlarged, rate of growth may be reduced, and adverse effects on reproduction and lactation may be noted. For these reasons, levels of rapeseed meal fed should not exceed the maximum levels that are recommended. It is generally recommended that for growing pigs to 25 kg in weight, 4% of the ration may be composed of rapeseed meal while for growing pigs from 25 to 90 kg in weight, up to 10% of rapeseed meal may be used in the ration. For breeding stock during gestation and lactation it is suggested that the level of rapeseed meal used should be restricted to a maximum of 3% of the ration.

The use of rapeseed meal in rations for poultry has increased greatly in recent years. Although the feeding of high levels of the meal causes some enlargement of the thyroid glands of poultry with the degree of enlargement increasing as the level of rapeseed meal in the ration is increased, it does not appear that poultry are too sensitive to the goitrogenic agents of rapeseed. Rate of growth, egg production, fertility, hatchability and livability of chickens and turkeys are apparently not affected by the changes that occur in the thyroid glands. As a consequence the need for caution in the use of the meal is less than is the case with swine.

On the basis of extensive experiments with poultry, it is generally recommended that levels as high as 10 to 15% of rapeseed meal may be included in starting and growing rations and as much as 10% may be used in rations for laying and breeding chickens and turkeys. When prepress-solvent, solvent or expeller meals processed at low temperatures are used at recommended levels the protein has been found to be approximately equivalent to that of soybean meal when energy–protein relationships are kept constant. It should be emphasized, however, that care must be taken that the level of lysine in the ration does not become a limiting factor because the protein of rapeseed meal only contains approximately 90% as much lysine as does the protein of soybean meal.

The future of rapeseed meal as a protein supplement for various classes of farm livestock appears bright. Progress that has been made in improving the quality of rapeseed meal and increasing our understanding of some of the basic factors affecting quality would warrant a prediction that rapeseed meals of the future will be much superior to those now being produced. The improvement in quality should lead to increased usage of rapeseed meal in the years to come.