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L.-A. APPELQVIST, Program Chairman

Agricultural and Genetic Potentials of Cruciferous Oilseed Crops[1,2]

R.K. DOWNEY, Research Station, Canada Agriculture, University Campus, Saskatoon, Saskatchewan, Canada

Abstract

Oilseed crops of the Cruciferae are widely adapted and are of particular importance to countries in the northern latitudes. Cruciferous seed oils from the crops, rapeseed, mustard, Camelina, oilseed radish and Crambe, enter edible or industrial markets, or both. The oilseed meal can be used either as a high protein feed supplement or as an organic fertilizer. The spring and winter forms of the two species of rapeseed, *Brassica napus* and *B. campestris,* are commercially the most important. Advances in crop management and plant breeding have resulted in a 40% to 50% increase in seed yield over the past 25 years. In the next 10 to 15 years, application of newer plant-breeding techniques will result in varieties even higher in yield and seed with improved oil and meal quality. Some of the quality improvements will be new patterns in fatty acid composition, higher oil and protein content, lower fiber content, and removal of the undesirable glucosinolate compounds from the meal. The mustard crops *Brassica juncea* and *B. hirta* are important condiment crops which have considerable potential as edible oil sources. Oilseed radish, *Raphanus sativus,* yields significantly less seed and oil than other cruciferous oil crops but its oil, which contains a low level of erucic acid (3.7%) and a relatively high content of 16-carbon fatty acids (9.3%), may be useful in blending with normal or zero erucic acid rapeseed oils. *Camelina sativa* or false flax has many desirable agronomic characteristics but the oil of Camelina seed contains too high a level of linolenic acid (36%) to penetrate the edible oil market and too low to compete industrially with linseed oil. *Crambe abyssinica* and *C. hispanica* are potentially important producers of high erucic acid industrial oils. Factors limiting Crambe development are the high cost of seed transportation due to the high volume to weight ratio of the threshed seed and the need for extra seed processing steps to render the meal suitable as a high protein feed supplement for livestock and poultry.

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[2] Contribution No. 425, Research Station, Canada Department of Agriculture, Saskatoon, Saskatchewan, Canada.

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Introduction

Vegetable oils, meals and seeds are the most important group of agricultural commodities, in terms of value, in world trade (8). The cruciferous oilseed crops play a significant role in this international market. The importance of these crops is further enhanced by their wide adaptation. They are cultivated from the northernmost farming areas of Canada and Europe to the subtropics. Several genera of the Cruciferae family contain oilseed crops which are or have been under commercial production and appear to have potential for further development (Table I).

The oils and meals from unselected populations of rapeseed, mustard, Camelina, Crambe and oilseed radish have several common characteristics which tend to set them apart from other vegetable oil crops. Economic crop plants of the Cruciferae produce seed oils which differ from most other vegetable oils in that they contain significant amounts of the long chain monoene fatty acids, eicosenoic and erucic, and low concentrations of saturated acids. These oils enter either the edible or industrial markets or both. The protein quantity and quality of Cruciferae meals obtained following oil extraction is high (26). The meal is used mainly as a high protein feed supplement for livestock and poultry and in Asian countries, as an organic fertilizer. These seed meals are characterized by the presence of one or more sulfur compounds called glucosinolates. The extent to which cruciferous oil meals may be successfully fed to nonruminant animals depends largely on the level and kind of glucosinolates present in the seed and the conditions and process of oil extraction (5–7,29,33).

Rapeseed

By far the most important oilseed crops of the Cruciferae are the two species of rapeseed, *Brassica napus*, commonly known as rape, colza or Argentine-type rape, and *B. campestris*, or turnip rape. In international trade the term rapeseed encompasses the seed of both of these species.

Rapeseed is a major commercial crop in over 28 countries. In many of these countries it is of considerable economic and political importance since it is the only edible oil crop that can be consistently and successfully grown in the more rigorous climates of the temperate zone, a factor of some significance to countries such as Sweden, Denmark, Poland, Chile and Canada. The insertion of the rapeseed crop into the usual European cereal-grass rotation is also an important factor in continued high cereal yields since it arrests the build up of cereal insects and diseases.

Each of the two species of rapeseed has a spring and winter form. The dominant crop in Europe, Japan and Chile is the biennial or winter form of the *B. napus* species, which is sown in the fall and harvested early the following summer. In Canada, India and Pakistan the spring form of the *B. campestris* species constitutes the major acreage.

Rapeseed is a cool season crop and in areas adapted to its production, returns are usually equal to wheat. However, the risks from diseases, insects and frost are somewhat higher for rapeseed. Average European yields for winter rape (*B. napus*) are approximately 2,500 lb/acre, while Canadian yields of spring rape and turnip rape are close to 1,000 lb/acre. Under near ideal conditions, however, yields of over 6,600 lb/acre of winter and 4,000 lb/acre of spring rape are possible. Modern agronomic practices and improved varieties developed over the last 25 years have resulted in a 50% increase in European seed yields and a 40% increase in Canadian yields (13). Half the Canadian increase has occurred in the past 10 years. These yield advances have been very important in establishing the crop and ensuring continuity of seed supply.

TABLE I

Cultivated Oilseed Crops of the Cruciferae

Common name	Species name	Chromosome No. (diploid)
Rape	*Brassica napus* L.	38
Turnip rape	*B. campestris* L.	20
Oriental mustard	*B. juncea* (L.) Coss.	36
Brown mustard	*B. juncea* (L.) Coss.	36
Yellow mustard[a]	*B. hirta* Moench	24
Oilseed radish	*Raphanus sativus* L.	18
False flax	*Camelina sativa* Crantz	40
Crambe	*Crambe abyssinica* Hochst. ex R. E. Fries	90
Crambe	*C. hispanica* L.	60

[a] Synonymous with White Mustard and *Sinapis alba* L.

Although realizing that continued yield advances must be made, the plant breeder is now expending much more of his efforts to provide industry with a more competitive product. Rapeseed is on the verge of a revolution in quality. By 1980 to 1985 the rapeseed plant may look much as it does today, but its seed and byproducts will have undergone drastic changes in their chemical make up and appearance.

The first change will be in the fatty acid composition of rapeseed oil. Rapeseed varieties of both species, which produce seed oils very low in erucic acid content, will replace the present varieties which have medium to high erucic acid contents (Table II). Although high erucic acid oils have special industrial applications and margarine manufacturers prefer levels of 10% to 25% erucic acid (30), nutritional studies suggest that very low erucic acid levels are preferred (1,4,40). To this end Canada expects to have sufficient seed of low erucic acid varieties to sow up to 4 million acres by 1972. Sweden, Germany and other European rapeseed-producing countries are also expected to move towards low erucic acid varieties. The agronomic performance of Canadian low erucic acid strains and varieties of spring rape and turnip rape indicates that they can successfully replace the present varieties. The oil percentage of the selections are slightly lower than the varieties from which they were bred. This may be due at least in part to the substitution of the 18-carbon atom oleic acid molecule for the eicosenoic and erucic acids with 20- and 22-carbon atoms respectively.

The conversion to low erucic acid varieties in Europe will be slower than the Canadian conversion in that winter hardiness appears to be closely linked genetically with the genes for high erucic acid production (34). It should be only a matter of time and

TABLE II

Per Cent Fatty Acid Composition of Standard Spring and Winter Rapeseed Varieties and Selections Low in Erucic and Eicosenoic Acids

Species variety and habit[a]	Carbon chain length and degree of saturation										
	16:0	16:1	18:0	18:1	18:2	18:3	20:0	20:1	22:0	22:1	24:1
Brassica napus											
Victor (W)	3.0	0.3	0.8	9.9	13.5	9.8	0.6	6.8	0.7	53.6	1.0
Target (S)	3.0	0.5	1.5	20.9	13.9	9.1	0.5	12.2	Trace	38.6	0
Oro (S)	4.8	0.5	2.4	63.1	19.4	9.0	Trace	0.8	0	0	0
Brassica campestris											
Duro (W)	2.0	0.2	1.0	12.9	13.4	9.1	0.7	9.6	0.2	49.8	1.1
Echo (S)	4.5	0.3	1.3	33.3	20.4	7.6	0.5	9.4	Trace	23.0	0
Zero selection (S)	3.1	0.2	1.6	64.5	21.2	9.2	0	0	Trace	0	0

[a] Habit: W, winter annual; S, spring-sown annual.

TABLE III

Average Agronomic Performance of Spring-Sown Rapeseed and Commercial Mustards in Western Canada, 1967 to 1969

Crop and kind	Species	Relative yield, %	Oil, %	Meal protein, %[a]	Days to mature
Rapeseed					
Rape	*Brassica napus*	100	42.2	47.0	101
Turnip rape	*B. campestris*	96	40.3	45.0	84
Mustards					
Oriental	*B. juncea*	114	37.7	49.2	93
Brown	*B. juncea*	111	35.7	46.0	93
Yellow or White	*B. hirta*	90	26.9	49.5	89

[a] Protein calculated on an oil-free moisture-free basis.

effort before this linkage is broken and low erucic acid strains with good resistance to winter killing are available.

Low erucic acid rapeseed oil from the Oro variety has been commercially evaluated in Canada and found to have desirable physical and nutritional qualities (25,36). Thus it is expected that low erucic acid oils will move quickly onto the market.

The only likely visible change in the rapeseed crop of the future will be in the color of the seed coat. All rapeseed varieties today, with the exception of the yellow Sarson varieties from India, have black to reddish-brown seed coats. Recently it has been shown in turnip rape (*B. campestris*) that yellow-seeded forms from the same genetic background contain about 1.9% more oil than brown-seeded strains, and the oil-free meal contains 3.2% more protein and 4.6% less fiber (31). Similar differences have been found between yellow- and brown-seeded mustard (*B. juncea*) (S.H. Pawlowski, private communication). Agronomically the yellow-seeded selections appear to be equal in performance to the brown-seeded material from which they were selected. Work is progressing rapidly to combine the desirable features associated with yellow seed and the low erucic acid characteristic. When this is accomplished the yellow seed will serve as identification for low erucic acid oil-bearing seed.

The third change which is under way is the elimination of the undesirable glucosinolates in rapeseed and rapeseed meal. Enzyme hydrolysis of these compounds produces 3-butenyl- and 4-pentenyl-isothiocyanates and oxazolidinethione. It is these and other breakdown products which can cause metabolic upsets in nonruminant animals (5,7,39). Proper extraction procedures prevent glucosinolate breakdown but elimination of these compounds through plant breeding will allow a higher level of usage in all animal feeds. Agronomically acceptable strains of spring rape (*B. napus*), essentially free of rapeseed glucosinolates, have been developed in Canada, but again it is necessary to combine this characteristic with that of low erucic acid oil. Other developments which may occur in the more distant future are the production of varieties which have no chlorophyll in the cotyledons of developing seeds but which will turn green on germination. This achievement would eliminate potential green oil problems. Breeding stock with this characteristic has been isolated by G.R. Stringam at the Saskatoon Research Station (private communication). Lower linolenic acid content should also be possible but progress on this objective has been slow (12,37,38). Kondra and Stefansson (19), however, have shown that it is possible to increase the level of linoleic acid in spring rape without increasing the linolenic content. Preliminary work on proteins in turnip rape also suggests that through selection and hybridization it is possible to alter the relative proportions of the various proteins and to influence the amino acid composition within some of these proteins (A.J. Finlayson, private communication).

Successful production of haploid rape plants from anther tissue culture by K. Murakami and T. Shiga of the National Institute of Agricultural Sciences, Division of Genetics, Hiratsuka, Kanagawa, Japan, now gives the plant breeder a powerful tool in identifying the desired genotypes so necessary to make continued genetic advances. Further yield improvement is also likely to occur through the use of hybrids utilizing cytoplasmic male sterility or the self-incompatibility alleles present in the *B. campestris* species. To date, rapeseed breeders have given this area only superficial attention.

Mustards

Two other *Brassica* species usually considered spice or condiment crops are potential producers of edible oils. Yellow or white mustard seed (*B. hirta* or *Sinapis alba*) is usually used in the manufacture of prepared mustard and as a meat extender in the United States prepared-meat industry. Sweden, however, has found the oil from yellow mustard superior to rapeseed oil for certain products. Over 5000 metric tons of yellow mustard seed were grown and processed for oil in Sweden in 1970. The meal is apparently used in cattle feed despite the presence of high levels of the glucosinolate.

Agronomically, yellow mustard is an attractive crop. It is easily grown and handled with small grain equipment, is resistant to seed shattering, and requires only a short growing season. Oil content of yellow mustard is usually significantly below that

TABLE IV

Per Cent Fatty Acid Composition of Seed Oils From Minor Cruciferae Oilseed Crops Grown in Western Canada

Crop or species	Carbon number and degree of saturation												
	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:0	20:1	20:2	22:0	22:1	24:1
Oriental mustard[a]		3.8			21.8	20.3	14.1	Trace	15.0	0	Trace	25.1	
Brown mustard[a]		3.9			23.0	20.6	14.8	Trace	13.9	0	Trace	23.8	
Yellow mustard[a]		3.0			20.4	8.3	11.6	Trace	11.8	0	Trace	45.0	
Camelina[b]		5.0	Trace	2.1	14.8	16.4	36.1	0.4	17.5	2.3	1.7	3.7	
Oil Seed Radish		7.1	2.2	Trace	40.0	16.9	14.5	0.4	9.3	0	Trace	9.6	
Crambe abyssinica[c]	0.1	1.7	0.3	1.0	16.7	7.8	6.9	1.3	2.9	Trace	2.7	55.7	2.9
C. hispanica[a]	0.1	3.7	0.4	0.9	20.1	10.7	5.5	Trace	4.6	0	1.6	52.4	

[a] After B.R. Stefansson. A survey of the chemical composition of the 1969 crop of mustard in Canada. Federal Grain Limited, 1970. Note that the content of palmitoleic and stearic were included in palmitic and oleic values respectively.
[b] After Plessers et al. (32).
[c] After McGregor et al. (23).

of other *Brassica* oil crops. In Europe the seed yield is usually higher and in Canada lower than alternative spring-sown *B. campestris* crops (Table III).

Interspecific crosses between yellow mustard and other Cruciferae oil crops have not been successful. This species isolation will tend to restrict the genetic advances toward higher seed and oil yields as well as new patterns in fatty acid composition and levels of glucosinolates which might be possible.

The *Brassica juncea* crops of brown and Oriental mustard are primarily used for the manufacture of hot or powdered mustard in Europe, North America and Japan. In India and Pakistan, however, the *B. juncea* crop rai is a major source of edible oil. In Japan too, about half the oil is removed from Canadian-grown Oriental mustard for edible uses prior to processing the meal for the condiment trade.

The oil content and agronomic performance of Canadian-grown brown mustard, and more particularly Oriental mustard, demonstrates the very real potential that these crops have as oil sources (Table III). These crops have greater drought resistance and a slight yield advantage over spring-sown rapeseed, and their fatty acid composition suggests that they could be utilized in products where rapeseed oil is now used (Table IV).

B. juncea meals have a high protein content but also contains sinigrin, a glucosinolate which gives rise to 8 to 10 mg/g of allyl isothiocyanate. It is the presence of this glucosinolate which has inhibited the exploitation of these mustards as oil crops. Processes have been described which render *B. juncea* meals suitable for livestock and poultry feeding but to date they have not been commercially adopted (15,27,28,43).

Adoption of these methods or removal of the glucosinolate, either through selection or interspecific crosses with glucosinolate-free forms of *B. napus*, appears to be the only barrier to development of this potential oil. Oilseed crops of three other Cruciferae genera have a more limited potential but warrant consideration.

Oilseed Radish

Oilseed radish, *Raphanus sativus* L., is simply the radish plant which has been selected for seed and oil yield rather than for its edible root. Until a few years ago this crop was grown on a limited acreage in Poland and a few other European countries. Today the crop has all but disappeared from cultivation. Seed and oil yields are not equal to spring rape but the fatty acid composition of the oil with its relatively low level of erucic acid and its higher content of 16-carbon fatty acids is of significance (Table IV). Extensive meal use in animal feeds would undoubtedly require processing treatments similar to that proposed for the mustards to improve its acceptability and palatability as an animal feed.

Camelina

Camelina sativa Crantz has been an important oilseed crop in several European countries (16,35,41). Many North American agronomists are familiar with only the weedy form of this species known as false or Dutch flax or gold-of-pleasure. The cultivated form, Camelina, is useful and productive. Its ability to mature early and produce on poor sandy soils makes it an attractive crop to farmers in northern latitudes. Trials in Sweden (2), Denmark (3), Poland (11), Russia (23), Canada (32) and Germany (45) show that the crop matures about 20 days earlier than flax and that yields of seed and oil from Camelina are equivalent to other spring-sown oil crops, such as rapeseed, and considerably more than flax. In addition, Camelina requires no special equipment other than that used in normal grain-growing operations.

Despite these advantages the acreage devoted to the crop has declined sharply. Although the small seed size (0.8 to 1.2 g/1000 kernels) is sometimes a problem, the major barrier to future exploitation of the crop is the fatty acid composition of Camelina oil (Table IV). In its present form, Camelina oil contains too high a level of linolenic acid to penetrate the edible oil market and too low a level to offer competition with flax. No concerted effort has been directed towards altering the level of linolenic acid and very little has been done to determine the array of fatty acid compositions which may be present in the Camelina genera.

The meal of Camelina is reported to contain 7.6% to 10.9% fiber (32) and over 40% good quality protein (20). On enzyme hydrolysis, glucosinolates in Camelina meals give rise to very little volatile isothiocyanates and no oxazolidinethione (10,32). However, Kjaer, Gmelin and Jensen (18) have isolated a nonvolatile 10-methylsulphinyldecyl isothiocyanate and a second unidentified glucosinolate from Camelina.

Feed trials with mice suggest that more Camelina meal could be tolerated in the nonruminant diet than rapeseed or Crambe meals, but that palatability problems could reduce feed intake at high levels (21). No investigations on the variability in glucosinolate content within the crop have been reported.

Today the Camelina cultivation in Europe appears to be reduced to small acreages in Poland where it is used as a replacement for winter killed rapeseed. The products of Camelina processing are blended off in rapeseed oil and meal. China must also grow some acreage since 12,000 metric tons were exported to Japan in 1969. The end use of this seed oil is not known but the meal probably was used as an organic fertilizer for tobacco and citrus fruits.

Crambe

Two species of the genus Crambe (*C. abyssinica* and *C. hispanica*) have obtained considerably publicity as a potential new industrial oil crop for the United States. It has also been tested and found agronomically acceptable in Canada and several European countries. Crambe is attractive to growers because it gives good yields in comparison to rape and flax (3,17,22,24,42,44), is attacked by few diseases and insects, and can be sown and harvested with small grain equipment (24).

Crambe may well develop as a specialty crop because its seed oil contains a high content of the fatty acid erucic (Table IV). The present and potential industrial uses for high erucic acid oils are discussed by Wolff and Nieschlag elsewhere in this group of symposium papers.

The factors limiting the Crambe development are the high volume to weight ratio in the threshed seed and the need for extra steps in seed processing to render the meal suitable as a high protein feed supplement for livestock and poultry.

The seeds of Crambe are spherical and are borne singly, weighing 7.0 to 7.5 g/1000 with a husk content of 14% to 20% by weight in Canada (24) and

25% to 40% in the United States (14). This husk cannot be easily removed at the farm level without damaging the seed and must therefore be transported to the extraction mill. Husked seed usually contains 33% to 54% oil and 30% to 50% protein (14,24). If husks are not removed the oil and protein are reduced accordingly and the fiber content of the meal is increased to about 16%.

The amino acid composition of Crambe meal indicates good nutritional quality but it contains sinapin (0.5%) and glucosinolates (8–10% calculated as *epi*-grogoitrin) which can reduce palatability and cause metabolic upsets in livestock and poultry (14,26). Since over half the byproducts produced on seed processing is meal, the economics of Crambe production hinge to a large extent on the value of the meal. Significant improvement in meal feeding value has been obtained through a soda ash treatment during processing (29) but additional processing costs over other oilseeds are thus involved.

The most efficient way of reducing hull content and glucosinolate levels is to build these characteristics into new varieties through plant breeding. Only limited breeding work has been undertaken with Crambe and the progress which might be made is hindered by the crop's high level of polyploidy. The basic chromosome number has been reported as 15, and the chromosome complement of *C. abyssinica* as 90, and *C. hispanica* as 60 (9). Thus the level of ploidy tends to mask the variability which may lie within the species. Work at the University of Indiana, where selection for larger, heavier seed was practiced in *C. abyssinica,* resulted in the variety Prophet in 1968. More recently, as a result of mass selection within the *C. hispanica* species, the Indy variety, purported to be higher in seed yield, has been released.

Despite the effort that has been devoted to commercial cultivation of Crambe, the only significant acreage grown at the present time is several thousand acres in the Western Canadian provinces of Manitoba and Saskatchewan. Whether the crop will continue to survive will depend largely on the economics of transportation from the farm to processing plant and a continuing increase in demand for high erucic acid oils. The recent decision of European rapeseed refiners to favor low erucic acid oils in edible products would appear to favor the development of Crambe as an easily identifiable high erucic acid seed source.

Discussion

The cruciferous oilseed crops have a tremendous potential, not only because they are easily cultivated with standard equipment but because of the great array of variation which resides within the various species. When and if the potential of these crops is exploited largely depends on the ease with which the plant breeder can modify the chemical make up of the oil and meal in the desired direction. Considerable progress has been made toward this end in the rapeseed crop, but in the minor cruciferous oil crops, very little effort has been expended to determine the range in chemical variation within the various species. Until this information is obtained the real potential of most of these crops lies hidden.

It is important to understand that advances, such as are being made in rapeseed oil and meal quality, are not done without some sacrifice. Each modification that is demanded by the industry reduces the genetic base or plant-to-plant variation within which the breeder must work. In addition, each new character which must be incorporated increases the task of the breeder expotentially. As a result, the development of a high-yielding, well-adapted variety, incorporating all the desirable quality factors, is much more difficult and time-consuming. It is essential therefore that careful examination be given to the need of a particular trait before it is imposed upon the crop and that such a restriction be retained only so long as it serves a useful purpose.

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