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RAPESEED & CRAMBE

ALTERNATIVE CROPS WITH POTENTIAL INDUSTRIAL USES

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RAPESEED AND CRAMBE: ALTERNATIVE CROPS WITH POTENTIAL INDUSTRIAL USES[1]

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ABSTRACT

A system method was used to analyze the potential United States market for high erucic acid (HEA) oils and meals from rapeseed *(Brassica campestris* and *B. napus)* and crambe *(Crambe abyssinica).* Analysis included production of seed, oil, and meal; commercial uses of oil and meal; and competition with other producing areas. Results indicate that rapeseed and crambe can be grown successfully in several parts of the United States, including Kansas. An estimated profitable price of 10.6 cents per pound for seed would require yields to average 1,286 pounds per acre. Such yields already have been attained in Kansas trials. HEA oil seed can be crushed in existing facilities. Rapeseed and crambe seed are less expensive to process than soybeans because of their higher oil content. Rapeseed and crambe meals can be used in animal feeds, but amounts will be restricted until the glucosinolate content is reduced or eliminated. The composition of HEA oil gives it unique and valuable properties for industrial uses, especially as a substitute for petroleum products. Europe and Canada produce mainly edible oil from rapeseed, so probably would not compete with the United States in developing HEA oil. The USDA has organized research efforts in several states, including Kansas, to establish rapeseed and crambe as commercial crops by promoting markets for HEA oil and meal. Kansas has advantages in location relative to transportation, facilities for crushing and refining, and a cattle feeding industry that could use the meal.

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INTRODUCTION

A crisis situation has developed in world agriculture. Production of traditional agricultural products is more than consumers can use. This has been the case particularly for wheat, corn, and soybeans for nearly 10 years. Competition is getting more intense because production has increased faster than consumption. So far, various government policies have subsidized all or part of the commodity system to protect both production (farmers) and the political power base by keeping consumers reasonably happy.

Another solution is diversifying agriculture to include alternative crops, particularly those that can be processed into more valuable products (value-added). This would not only reduce surpluses but also help to support the nation's industrial base and reduce imports.

Currently, the United States imports large quantities of rapeseed oil. An extensive breeding program in Canada has succeeded in developing varieties with little or no erucic acid (low erucic acid, LEA) and low levels of other toxic chemicals. The term "canola" was coined to identify the edible oil from these varieties (Thomas, 1984). Oil with high erucic acid (HEA) content, which is used in industry, also is derived from rapeseed and a related plant, crambe. Some HEA rapeseed has been produced in the United States since the 1940s primarily in Idaho. Crambe has been grown widely in demonstration plots but not commercially (USDA, 1989).

In 1986, the Agricultural Research Service and Office of Critical Materials, United States Department of Agriculture (USDA), convened a group to examine the potential of expanding an industry based on crambe and rapeseed with HEA content. That group now includes scientists from the University of Idaho, University of Illinois, Iowa State University, Kansas State University, University of Missouri, University of Nebraska, New Mexico State University, and North Dakota State University, plus representatives of the Kansas Board of Agriculture, the Northern Regional Research Center (USDA/ARS), and the Office of Critical Materials (USDA, 1989; Van Dyne et al., 1990).

General goals of the High Erucic Acid Oil Project are to diversify United States agriculture into new markets and to provide raw materials for industry. The specific goal is to establish crambe and rapeseed as commercial crops by developing markets for primary products and by-products. The procedure involves examining every related component from plant breeding to end-products. Because most rapeseed is planted in the fall and crambe in spring, both crops could be grown (probably in different areas) to provide a dependable supply of oil to industry.

The objective of this study was to investigate ways in which crambe and rapeseed can provide new agricultural products, with an emphasis on industrial uses of HEA oils. The potential for production, processing, and marketing in Kansas was considered. This detailed information will be useful to researchers involved in the USDA project.

METHODOLOGY

The general approach to developing a total market analysis for HEA oil is referred to as a system or value chain. This concept has been developed and commented on by Porter (1985). The basic framework of the system methodology includes all marketing functions from the time oilseed is purchased from growers until the final processed products are sold to consumers.

The concept of using HEA oil is fairly new. Different utilizations of oil (the buyer side of the system that actually will create the demand) rely on exploitation of scientific research. Sometimes, research results have never been tested in a commercial-sized plant. Thus, economic data are not readily available. Therefore, the market approach will be more in terms of quality rather than quantity.

Since the initial objective of this study is to find new outlets for agricultural products, farmers will represent the start of the system analysis. Before deciding to plant a nontraditional crop, producers must consider four factors: 1. demand for the product as reflected in its price; 2. availability and location of the nearest market; 3. cost of production; and 4. the crop's suitability to the local environment (Shroyer and Erickson, 1987). The basic question is whether returns from the crop will be more than the supply and demand. The world oilseed market is very complex, and price levels will be determined by world demand for oil and meal (Thomas, 1984). All of these factors will be considered in the analysis.

The next step in the system is the crusher and refinery that purchases oilseed from farmers. A study of this phase involves major outlets for the oil and meal and then potential utilizations and economic profitability of production.

Technical and economic data for using meal by-products will be presented. Then we will consider utilization of HEA oil, both current and potential markets. The buyer side actually reflects a derived demand for oil, which is converted into products used in industrial activities.

Forces that interact with the system influence the general equilibrium structure and competition level at each stage, as well as potential entrants. The combined effect of each of these factors can act as a regulative force on the system.

Finally, the system analysis will consider production and marketing areas, including potential development in Kansas. Estimating market conditions for products that haven't been produced in any great quantities is difficult. Many factors have to be assumed as constant because actual data are lacking.

AGRONOMIC CONSIDERATIONS

The first objective is to investigate the potential of growing crambe and HEA rapeseed varieties in the U.S. (especially in Kansas), the expected yields, and risks involved in their cultivation.

Descriptions of Plants

Rapeseed

Rapeseed is one of the world's major sources of edible vegetable oil. Unlike soybeans, peanuts, and most other oilseeds, rapeseed comes from several species belonging to the mustard family (Cruciferae or Brassicaceae). These species include: *Brassica napus* (rape), *B. campestris* (turnip rape), and *B. juncea* (brown mustard). Rapeseed often is used as a general term to describe different species that are quite close in appearance but sometimes very different in their chemical composition or botanical origin. The common names used for the different species depend on the country (Table 1).

The rapeseed species are cool-season annuals, generally adapted to Canada and the Great Plains (Shroyer and Erickson, 1987). Both winter and spring varieties are grown in the United States (Fig. 1). *Brassica napus* is relatively tall, late maturing, and mostly self-pollinated. *B. campestris* is shorter, earlier maturing, and mostly cross-pollinated (Brotemarkle et al., 1989). Flowers are small and yellow. Pods are narrow and about 1.5 inches long (Fig. 2), each containing 15 to 40 small, round seeds (depending on variety and environment) (Hougen and Stefansson, 1983).

Crambe

Crambe abyssinica, native to countries around the Mediterranean region, has long been known to produce a high level of erucic acid. An extended research program, conducted mainly at Purdue University, led to development of improved seed yields, quality, and cultivars. The general areas of adaptation for crambe are Canada, northern Great Plains, Midwest, and Southeast (Shroyer and Erickson, 1987).

Crambe also belongs to the family Cruciferae or Brassicaceae. It is an erect, annual herb with large, pinnately lobed leaves (Fig. 3). Plant height varies from 60 to 90 cm (or taller) depending on the season and the population density. Flowers are white and very small. The spherical pods are usually one-seeded and indehiscent (Fig. 4). Seeds are about twice the size of rapeseed. The adherence of the hull at harvest facilitates separation of crambe from other small seeds.

In the United States, crambe and Abyssinian mustard are used as common names for this species. Crambe may be referred to as Abyssinian kale, colewort, or katran in other countries.

Table 1. Common names used for different species of rapeseed

Latin	Correct English	English Synonyms	Canadian	French	German
Brassica napus subsp. *oleifera*					
f. *annua*	summer rape	oilseed rape	–	colza d'été	sommerraps
f. *biennis*	winter rape	oil rape, Swede, rapeseed	Argentine rape	colza d'hiver, colza de printemps	winterraps
Brassica campestris subsp. *oleifera*					
f. *biennis*	winter turnip rape	rapeseed, oil turnip	Polish	navette d'hiver	winterrübsen
f. *annua*	summer turnip rape	rapeseed, oil turnip	–	navette d'été	sommerrübsen
var. *chinensis*	summer turnip rape	Chinese mustard	–	moutarde Chinoise	Chinasenf
var. *dichotoma*	summer turnip rape	toria	–	toria	toria
var. *pekinensis*	summer turnip rape	celery cabbage, Chinese cake	–	chou chinoise	Chinakohl
var. *trilocularis*	summer turnip rape	sarson	–	sarson	sarson
Brassica juncea	brown mustard	leaf mustard, Indian mustard	Oriental mustard	moutarde brune	brauner senf, sarepta senf

Data from Appelqvist and Ohlson (1972)

Figure 1. Rapeseed in flower

Figure 2. Rapeseed fruits

Figure 3. Crambe in flower

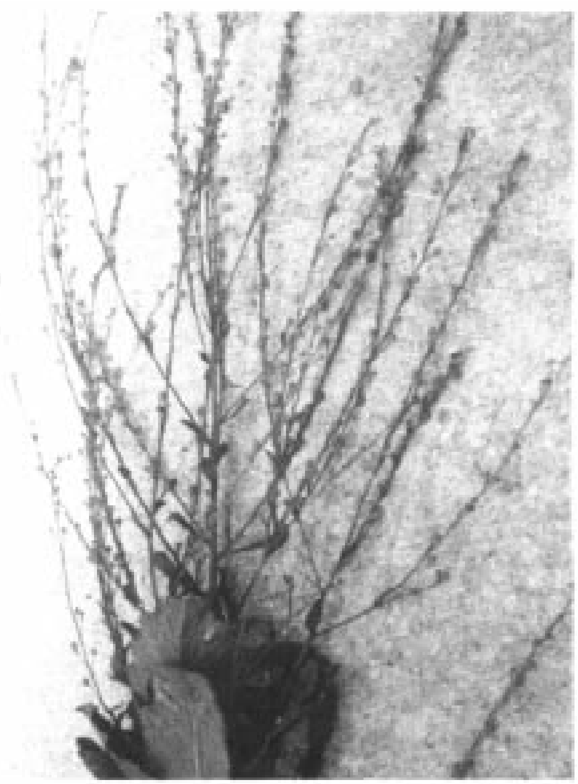

Figure 4. Crambe fruits

Cultivation Characteristics

Details about rapeseed cultivation practices are available in several publications (Appelqvist and Ohlson, 1972; Kramer et al., 1983; White and Higgins, 1966), so only major points will be reviewed here. Many rapeseed varieties currently grown around the world are primarily cross-pollinated. Therefore, these species are rather variable. This variation along with a large number of varieties provide rapeseed with the ability to adapt to different environmental conditions. The wide adaptability of HEA oil varieties is encouraging for potential development in the United States.

Rapeseed is cultivated around the globe, at various latitudes and under extreme climates. For instance, it can be grown in Sweden and Finland, where it survives under snow cover for a long period of time; above the Arctic circle, with 24 hours of light a day in summer; or in Pakistan, where day length is less than 10 hours in winter. In some growing areas, there is almost no rainfall during the growing period, whereas in others, such as Holland and France, winter and spring are very humid (Appelqvist and Ohlson, 1972).

Rapeseed should be planted shallowly. Seedlings need sufficient surface moisture and loose soil for establishment (Fig. 5). Planting in Kansas can vary from mid August in the northwest to mid September in the southeast for the winter varieties (Brotemarkle et al., 1989). A study at Colby, Kansas using two planting dates showed a clear advantage in seed yield with the earlier date (Aug. 30). Earlier planting also reduced winter kill (Robertson, 1986a).

Other variables of row spacing and seeding rate also were studied at Colby (Robertson and Sunderman, 1987). The best yields were obtained from plants in 12-inch rows and a seeding rate of 4 lbs/acre.

According to recent experiences, rapeseed can tolerate soils with a wide pH range and can be grown on marginal soils, which would not be rich enough for wheat. Furthermore, rapeseed seems to be very tolerant of saline conditions (Appelqvist and Ohlson, 1972; Kramer et al., 1983).

Winter rapeseeds suffer less from drought in summer than winter wheat, which has a shallower root system (Appelqvist and Ohlson, 1972). Conditions of excess moisture may lead to fungal attacks on the roots and decrease resistance to low temperatures in winter. Also, excess flooding may damage the crop, especially in the earlier stages of development. However, any lack of water during the reproductive phase may greatly decrease the formation of seeds, seed size, and oil content (Delaye, 1967).

Relative to other oilseed crops, rapeseed requires low temperatures. In the reproductive phase, the plant develops a greater tolerance to high temperatures, but high

Figure 5. Seedlings of rapeseed

Figure 6. Rapeseed showing insect damage to leaves

heat in combination with drought may result in a reduction in seed size and oil content (Appelqvist and Ohlson, 1972).

Rapeseed can be attacked by a number of diseases and insects (Fig. 6). At present, Treflan is the only insecticide labelled for use with rapeseed (Van Dyne et al., 1990). Crop rotation and destruction of volunteer plants will help reduce insect populations.

Crambe is also a cool-season, annual crop. Medium-light to heavy soils that are fertile and well drained are suitable for crambe production. The crop is planted in spring and matures in about 100 days. Although crambe has fewer pests than rapeseed, rotation with other crops is recommended to avoid a buildup of insects and disease. Crambe should not succeed itself or related crops (rapeseed or mustard) in a rotation (White and Higgins, 1966). The resistance of crambe to drought depends on the variety; however, it can be considered as drought-tolerant. This quality also can be enhanced by genetic selection (Castaneda, 1983). Breeding has resulted in varieties with larger seeds, greater seed yields, and lower content of glucosinolate. Since some commercial fields were affected by a disease in the 1960s, efforts have been made to develop germ plasm that is more tolerant to the disease (Röbbelen et al., 1989). However, K. J. Lessman[3] estimated that our knowledge of the technical and scientific background of requirements for crambe production is enough to grow it on a commercial scale. More information will be obtained from the experience of growers as the crop is planted over a wider area with different climatic conditions.

Planting and harvesting of crambe and rapeseed are done with conventional farm equipment normally used for wheat, oats, barley, and other small grains (Fig. 7). Thus, no additional investment in equipment is necessary. Harvest of these crops is normally completed in early June in Kansas. Double cropping with soybeans is possible in areas where beans following wheat have been successful.

The following list shows the breakdown of responses received from a survey conducted in the United Kingdom to evaluate crop damage associated with rapeseed cultivation (Burns, 1982): no damage, 7.3 percent; bird damage, 25.6 percent; harvesting problems, 18.7 percent; control of pests and disease, 18.3 percent; drying and storage, 10.6 percent; weed control, 4.0 percent; and other disadvantages, 15.6 percent. The bird damage can be overcome as it has been for other crops. The other problems probably were attributable to lack of experience in growing rapeseed.

Clearly, neither rapeseed nor crambe has any specific or selective requirements that would present a barrier to introducing them widely in many areas of the United States, including Kansas (Shroyer et al., 1987). In fact, their agronomic suitability for many regions is a major advantage of these crops (Meister and Sims, 1984).

[3] Ann. Rep. High Erucic Acid Oil Manage. Comm., Kansas City, MO., Aug. 1988.

Figure 7. Planting rapeseed at Colby, Kansas

Table 2. Seed yields of four winter rapeseed varieties with HEA, grown at seven locations during 1985-86

Location	Rapeseed Varieties				Average
	Bridger	Dwarf Essex	Idaho Fuel	Indore	Yield, Location
	–lbs/acre–				
Northwest					
Idaho	5,546	7,605	5,753	4,257	5,790
Washington	4,045	5,298	3,766	3,689	4,199
Southeast					
Georgia I	1,214	–	928	1,121	1,088
Georgia II	1,262	289	1,017	1,151	929
Mississippi	1,224	726	974	884	952
South Carolina	1,103	756	1,217	1,170	1,061
Virginia	923	502	747	774	737
Average yield, variety	2,188	2,529	2,057	1,864	–

Data from Auld et al., 1986

National Variety Trials

The University of Idaho estimated some potential yields and quality characteristics of HEA rapeseed varieties for the United States in 1985-86 (Auld et al., 1986). Table 2 shows a wide range of yields, demonstrating the great variability of rapeseed in different environments. All four varieties had the best yields in the Northwest, probably because of the long vernalization requirement. Bridger produced higher yields than any other variety in the Southeast.

In 1982, the Colby Branch Experiment Station in Kansas joined the National Winter Rape Variety Trial. Eleven varieties were grown in the first year; later, the test was expanded to 35 varieties. Seed yields were quite variable, but in one test, Bridger (HEA oil) ranked among the top five varieties for yield (Robertson, 1986b).

Ten varieties were evaluated in 1987-88 (Lawless, 1989). Seeds were planted at a rate of 7 lbs/acre on Sept. 1, and plants were harvested on June 24. Cascade had significantly lower seed yield than the other varieties. The highest yield was 1,382 lbs/acre, and the average for all varieties was 1,272 lbs/acre. Dwarf Essex, Bridger, and Bienvenue had the highest oil content, near 40 percent. In a trial at Hutchinson, KS, yields were lower, but oil content was over 40 percent (Table 3.)

Table 3. Rapeseed variety trial, Hutchinson, KS, 1987

Variety	Yield lbs/acre	Glucosinolates percent	Erucic Acid percent	Oil percent
H47	1,115	4.7	47.1	41.4
Gorczanski	1,034	4.5	46.1	42.4
Dwarf Essex	874	4.2	48.1	41.0
Indore	856	4.0	42.3	42.7
Bridger	813	3.0	50.8	41.9
Average	938	4.1	46.9	41.0

Annual Report, South Central Experiment Field, Kansas State Univ., unpublished.

On a commercial scale, average yields of 2,000 lbs. per acre would be expected for rapeseed. This amount would produce about 1,200 lbs. high protein meal and 800 lbs. oil (half erucic acid and half other fatty acids). Crambe should yield about 1,500 lbs. of seed per acre, providing 975 lbs. meal and 525 lbs. oil (about 60 percent erucic acid) (Van Dyne et al., 1990).

Oil content is often a good indicator of maturity of the seed at harvest. We must be keep in mind that oil is the main product. The objective is to produce both large quantities and a good quality of oil. According to Table 4, there are no significant differences among the different species or various locations in oil content. The fact that location does not significantly influence oil content was reported in previous studies by Meister and Sims (1984) and Appelqvist and Ohlson (1972).

In experimental conditions, the need to harvest prior to full maturity to avoid excessive seed shatter often results in oil contents lower than those usually observed for commercial rapeseed crops (Auld et al., 1986). The average oil yield for industrial varieties in commercial production is roughly 44 percent.

Erucic acid is one of the major factors to be considered in rapeseed production. The erucic acid content gives the oilseed most of its valuable characteristics. The richer an oil is in erucic acid, the better its quality and the greater its marketability for industrial purposes.

Location does not seem to influence the percentage of erucic acid in the extracted oil (Table 5). The differences observed were not significant. However, Bridger contained a higher average level of erucic acid than the other varieties tested.

Glucosinolate content is measured in the meal after the oil extraction process. It is a very important factor, because it affects the value of this by-product of rapeseed. Glucosinolates can be hydrolyzed into antinutritional factors (thiocyanates, isothiocyanates, or nitriles) that limit the incorporation of rapeseed or crambe meal as a protein source in animal rations. These factors reduce palatability and may cause goiter by adversely affecting iodine uptake by the thyroid gland (Röbbelen et al., 1989). The less glucosinolate a meal contains, the greater its nutritional and marketable value.

Data shown in Table 6 indicate that Dwarf Essex rapeseed meal had considerably higher glucosinolate content than the other varieties, except in the state of Washington. No explanation was given for this situation. Meal from the three other varieties might not cause any antinutritional problems, if incorporated at a reasonable proportion in animal rations.

Summary

Tests showed that rapeseed, including varieties with HEA oil, can be grown successfully in Kansas. Basic agronomic practices have been established, requiring no specialized equipment. Evaluation of rapeseed varieties involves consideration of yield and quality of both meal and oil. Quality components of individual varieties influence both the potential market and the price. Location does not seem to significantly influence content of either erucic acid or glucosinolates, which are more specific to the varieties. Bridger was highest in both seed yield and erucic acid content and also had a low level of glucosinolates. These characteristics place it among the best varieties in terms of potential industrial uses.

Table 4. Oil content of four winter rapeseed varieties grown at six locations during 1985-86

Location	Rapeseed Varieties				Average Content, Location
	Bridger	Dwarf Essex	Idaho Fuel	Indore	
	–percent–				
Northwest					
Idaho	41.0	40.8	41.8	41.7	41.1
Washington	42.0	42.9	42.2	39.9	41.8
Southwest					
Georgia	40.0	–	38.2	38.3	38.8
Mississippi	43.7	41.1	43.1	41.8	42.4
South Carolina	39.6	36.5	38.6	38.6	38.1
Virginia	38.2	35.9	39.2	38.7	38.0
Average content, variety	40.8	39.4	40.5	39.5	–

Data from Auld et al., 1986

Table 5. Erucic acid content of oil extracted from four winter rapeseed varieties grown at seven locations during 1985-86

Location	Rapeseed Varieties				Average Content, Location
	Bridger	Dwarf Essex	Idaho Fuel	Indore	
	–percent–				
Northwest					
Idaho	49.2	50.3	47.8	47.6	48.7
Washington	50.4	46.7	39.8	47.7	46.1
Southeast					
Georgia I	53.5	–	44.9	49.4	49.2
Georgia II	50.2	47.7	47.3	48.5	48.4
Mississippi	48.8	45.3	49.2	48.6	48.0
South Carolina	47.2	48.4	42.5	40.5	44.7
Virginia	55.0	55.5	36.7	51.5	49.7
Average content, variety	50.6	48.9	44.0	47.7	–

Data from Auld et al., 1986

Table 6. Glucosinolate content of four winter rapeseed varieties with HEA, grown at eight locations during during 1985-86

Location	Rapeseed Varieties				Average Content, Location
	Bridger	Dwarf Essex	Idaho Fuel	Indore	
	–μmole/gram–				
Northwest					
Idaho	21.2	105.6	12.8	4.2	36.0
Washington	11.6	15.0	9.0	6.4	10.5
Southeast					
Georgia I	14.2	–	16.2	8.5	13.0
Georgia II	14.8	78.9	8.2	14.8	29.2
Mississippi	12.9	112.3	27.3	10.6	40.8
North Carolina	18.7	41.1	33.5	7.4	25.2
South Carolina	–	81.6	13.1	9.4	34.7
Virginia	10.5	109.9	16.6	7.4	36.1
Average content, variety	14.8	77.7	17.0	8.6	–

Data from Auld et al., 1986

COST OF PRODUCTION

Variable and Fixed Costs

The following cost study estimates the feasibility of producing crambe and HEA rapeseed in the United States. The costs associated with fertilizers, seed, labor, and pesticides were compiled from a group analysis (Meister and Sims, 1984) and from a recent study by D.L. Van Dyne, M.G. Blase, and J.L. Dauve.[4] However, some costs for crambe were estimated because actual data do not exist. Other costs were derived using wheat as a basis, because most costs are quite comparable.

Fixed costs related to land and machinery were assumed to be the same as those for wheat (Table 7). Variable costs represented 49 percent of total input costs. Fertilizer is usually a major component, with an average cost of $18.76/acre (28 percent of variable costs). Pesticide spraying costs averaged $8.40/acre (13 percent of variable costs). Seed costs averaged $6.67/acre (8 percent of variable costs). A small part of the total planted area was not harvested because of poor stand establishment or bird damage. However, costs incurred for this area were included in the averages.

Total costs of production per acre for rapeseed and other crops currently grown in Kansas can be compared as follows: rapeseed, $136.01; winter wheat, $128.16; and sorghum, $134.75 (Van Dyne et al.;[4] Nelson and Langemeier, 1987b). More recent estimates for the midwestern U.S. are slightly higher ($142.76 for wheat, $146.56 for crambe, and $151.22 for rapeseed) (Van Dyne et al., 1990).

Break-even Prices and Yields

Assuming that costs for rapeseed production would be similar to those for wheat production, it is possible to estimate break-even prices/pound for three cultivation systems (Table 8), as well as a break-even yield/acre for a fixed price/pound (Table 9). Each of these tables can be recalculated as actual rapeseed production costs become available.

The break-even prices indicated are quite reasonable and in the expected range for the market. The market price of rapeseed in Kansas was about $5/bushel (the unit used for other crops) in 1986 (Witt, 1986). Given an

[4] Development, Technical Difficulties, and Economic Feasibility of Using Rapeseed and Crambe as Raw Materials for High Erucic Acid Oil. Meeting Amer. Inst. Chem. Engin., Denver, CO, Aug. 1988.

Table 7. Average costs per acre for producing rapeseed, crambe, and wheat

Activity	Rapeseed	Crambe	Wheat
Variable Costs, $			
Disk field	4.00	4.00	4.00
Nitrogen	8.00	6.40	6.40
Phosphate	4.00	3.80	3.80
Potash	2.80	1.92	1.92
Fertilizer application	1.00	1.00	1.00
Fertilizer incorporation	1.20	1.20	1.20
Seed	6.00	8.00	6.00
Grain drill	1.20	1.20	1.20
Fertilizer application	1.20	1.20	1.20
Pesticides	8.80	8.20	8.20
Combine	5.60	5.60	5.60
Hauling	1.92	2.80	2.40
Land	18.57	18.57	18.57
Miscellaneous	2.80	2.80	2.80
Total Variable Costs, $	67.49	66.69	64.29
Fixed Costs, $			
Real estate taxes	5.40	5.40	5.40
Interest on land ($741/ha × 2 × 6%)	35.58	35.58	35.58
Depreciation on crop machinery	19.60	19.60	19.60
Interest on crop machinery at 12%	8.30	8.30	8.30
Total Fixed Costs, $	68.52	68.52	68.52
Total Costs, $	136.01	132.81	132.81

Data from Burns, 1982; Nelson and Langemeier, 1987a; and D.L. Van Dyne, M.G. Blase, and J.L. Dauve. Development, Technical Difficulties, and Economic Feasibility of Using Rapeseed and Crambe as Raw Materials for High Erucic Acid Oil. Meeting Amer. Inst. Chem. Engin., Denver, CO, Aug. 1988.

average yield of 938 pounds per acre (Hutchinson, Kansas, Table 3), the break-even price would have to be 14.5 cents/pound. However, Van Dyne, Blase, and Dauve[4] estimated a profitable price of 10.6 cents/pound for HEA oilseed. This price would allow a comfortable margin to the producer in most cases and minimize the financial risks involved with this new crop. To achieve that price, yields would have to average 1,286 pounds/acre. Such yields already have been attained in Kansas trials (Lawless, 1989) and in northwestern states (Auld et al., 1986).

Summary

Expected yields of crambe and rapeseed in the U.S. are comparable to those in other producing countries and better in many cases. The costs involved are competitive, and the break-even study revealed a positive economic return for producing rapeseed, with a comfortable margin for the financial risks involved. To achieve a profitable price for seed, high yields must be maintained.

Table 8. Break-even costs for rapeseed production in three cropping systems, based on figures for wheat

	Cropping Systems		
Yield lbs/acre	Dryland Continuous	Summer Fallow	Irrigated
		–cents/lb–	
986	11.6	12.4	16.6
1,184	9.6	10.4	13.8
1,382	8.3	8.9	11.8
1,578	7.2	7.8	10.3
1,775	6.4	6.9	9.2
1,972	5.8	6.3	8.3
2,170	5.3	5.6	7.5
2,367	4.8	5.2	6.9

Table 9. Break-even yields of rapeseed for specific prices per pound, in three cropping systems

	Cropping Systems		
Price cents/lb	Dryland Continuous	Summer Fallow	Irrigated
		–lbs/acre–	
.05	2,589	2,784	3,699
.06	2,158	2,321	3,082
.07	1,849	1,988	2,642
.08	1,619	1,740	2,312
.09	1,438	1,546	2,054
.10	1,294	1,392	1,849
.11	1,177	1,265	1,682
.12	1,079	1,160	1,541
.13	996	1,071	1,422

PRODUCTION OF OIL AND MEAL

A minimal description of the industrial process will be presented in order to estimate various costs involved, equipment required, feasibility of establishing a plant, and regularity of the supply.

Crambe or rapeseed could be processed in most existing facilities that have traditionally been used for other oilseed crops. Most data provided in the following section are from typical plants, since data concerning HEA oil processing are not available. According to information from crushing plants, processing HEA and LEA varieties is comparable, both in terms of technique and costs (M.G. Blase, personal communication, 1988).

Constituents of Seeds

Rapeseed (Fig. 8) contains four major constituents: oil, water, protein, and fiber. Some of the important, minor constituents are free fatty acids, phosphatides (gum), enzymes (particularly myrosinase), and glucosinolates (Hougen and Stefansson, 1983). Erucic acid content is important to oil quality and for industrial use, whereas glucosinolate content is important for feeding quality of meal.

Crushing and extraction leave the oil almost unaltered, although some proteins may be denatured during processing. Sometimes, the denaturation can be con-

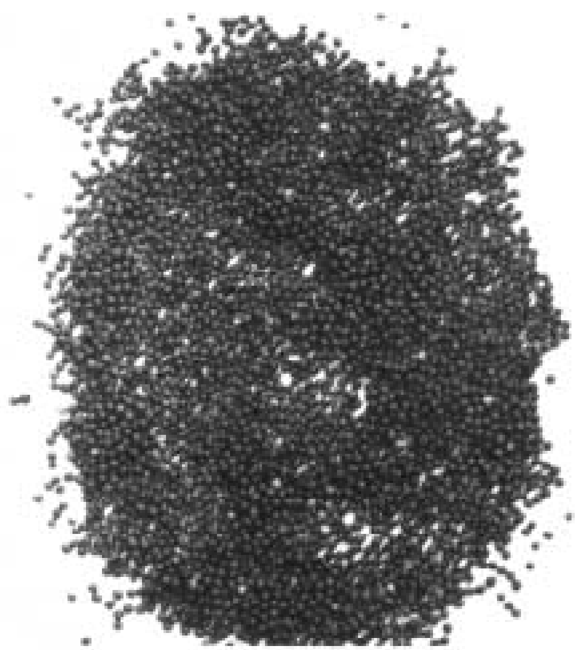

Figure 8. Rapeseed

trolled by toasting. This process is used particularly for soybean meal to destroy antinutritional factors. In the case of rapeseed, toasting improves the palatability of meal by destroying some of the bitter elements. Glucosinolate also may be changed into other compounds, either harmless or detrimental, depending on the processing conditions and methods.

The main objective of processing is to extract oil from the seed. Oil is the major product; however, the commercial value of the by-product makes it a source of revenue to help oil prices remain competitive. Thus, the second goal of processing is to provide a meal of good quality, i.e., one that contains as few antinutritional elements as possible.

Under certain conditions (presence of water, suitable catalyst, appropriate temperature), glucosinolates may be transformed into antinutritional factors. Unfortunately, all of these conditions are brought together in the meal: water; the enzyme, myrosinase (which serves as a catalyst); and a processing temperature that fits the reaction requirements. Crushing the seed is required to extract the oil but also results in contact between the glucosinolate, myrosinase, and water. The temperature at which the reaction becomes significant must be higher than 50° C, and reaction stops at temperatures above 85° C, which inactivate the enzyme.

Myrosinase resists deactivation when seed moisture levels are low. It has been known to survive processing temperatures of 88° to 93° C when seed moisture levels were 6 percent or less (Kramer et al., 1983; Baker et al., 1977; Campbell et al., 1984). For this reason, the industrial practice has been to quickly raise the temperature of the crushed seed containing at least 7 percent water. Once the temperature is above the deactivation level (85° C), then both temperature and moisture levels can be increased or decreased as required.

Preprocessing Requirements

Cleaning

Conventional grain cleaning equipment has proven to be well adapted for cleaning rapeseed. The first stage consists of scalping off any coarse material and then removing any cereal grains that may be present. The second and final stage consists of selectively removing and separating the undersized seed, as well as grains or particles that escaped separation in the first step. Air aspiration is employed at each stage. Rapeseed fragments may form part of the undersized material. Because they are rich in oil, recleaning for their recovery may be justified.

High capacity, dry screeners remove all materials that are over- or undersize, using a combinations of screens and aspirators. Magnets may be attached to remove any iron fragments (Röbbelen et al., 1989).

Dehulling

Hulls (fibrous seed coats) of both sunflower and soybean are easily stripped mechanically. This is not the case for rapeseed. Industry has not yet installed equipment that efficiently removes the rapeseed hull. This will be a limiting factor for the use of rapeseed and crambe meal in animal rations. However, it should be noted that some companies have used a cleaning system to lower the fiber content. Even if all the hulls are not removed, the product usually is called “dehulled rapeseed meal.”

Flaking

The objective of this step is to deform the seed by crushing and shearing in order to get a larger surface/volume ratio (a thin flake). The flakes are very fragile if they are thinner than 0.2 mm. If thicker than 0.3 mm, flakes are very difficult to process. Therefore, a common practice has been to flake the seed of most varieties between these two limits.

Cooking

The objective of cooking is to ease oil extraction. Cooked seed releases oil more readily than uncooked. The reason for this change is not fully understood. It seems to relate to properties of proteins, as well as the form, size, and viscosity of the microscopic oil units (Kramer et al., 1983). The cooking process results in a product with 2.3 to 3.5 percent moisture, which is a good range for further processing requirements.

Processing

Oil Extraction

There are three basic types of extraction processes (Scheithauer and Dripchak, 1988):

1. Mechanical extraction (pressing) is usually used in smaller facilities. In the pressing process, the cooked rapeseed flakes with about 3 percent moisture and 45 percent oil are passed through a continuous screwpress, which expels 75 percent or more of the oil. The oil content in the remaining cake is about 16 percent. This is a moderate pressing, which avoids a large increase in temperature that would denature most of the proteins.

The efficiency of crushing varies slightly according to the processor, variety, location, and growing environment. In crambe seed with 30 to 45 percent oil by weight, 29-44 percent of the oil will be extracted and for rapeseed with 40 to 45 percent oil, 39 to 44 percent will be extracted (Hairston et al., 1984; Kramer et al., 1983). Each 100 pounds of crushed rapeseed yields about 36 pounds of oil and 64 pounds of meal (Schermerhorn, 1986).

2. Solvent extraction is normally used with oilseed containing less than 25 percent oil. It is used in most soybean factories, which comprise a large portion of the industry. Residual oil after extraction is less than 1 percent.

The creation of intimate contact between solvent and oil in the seed takes time. The solution has to be passed repeatedly through a machine designed to incorporate the solvent by a staged countercurrent movement. Time is one of the major factors in this extraction process.

The common solvent is hexane, which readily dissolves vegetable oils. It has an appropriate boiling temperature, and its relatively low latent heat of vaporization helps conserve energy in the distillation stage. Furthermore, hexane is noncorrosive to metals. It is known to be neutral to the oil it dissolves (i.e., it does not chemically react with it). Additionally, hexane is chemically stable under the processing conditions and is readily available at moderate cost.

One of hexane's major disadvantages is its very high flammability. This requires the equipment to be designed, maintained, and operated within the safety range of flammable air/hexane mixtures. If hexane and air are mixed at the optimum proportion, they explode. Small explosions are sometimes inevitable in factories. However, an extraction plant must have very strict safety rules and very good equipment. The electric equipment must be explosion-proof, and any leak of hexane must be controlled immediately.

3. A prepress solvent normally is used for oilseed containing more than 25 percent oil (sunflower, flaxseed, etc.) and results in less than 0.5 percent oil in the cake after extraction.

Oil Settling and Filtering

The expelled press oil (with some suspended solid matter) is gravity settled in a screening tank. The settlings are continuously dredged off, drained, or repressed in various ways. They can be recycled back through the cooker for repressing. They can be repressed in a "foot" screw press, in which the cake is directed to the extraction unit with the main stream, and the expelled oil is recycled back to the screening tank. The dredges may go directly to the extraction unit with the main cake stream. The settled oil is continuously drawn off from the screening tank. The remaining, suspended fines are filtered or centrifuged.

Erucic Acid Extraction

Crambe oil is about 50 to 60 percent erucic acid by weight, whereas the proportion of erucic acid in the oil of HEA rapeseed varieties is about 45-44 percent (Princen and Rothfus, 1984; Hairston et al., 1984; Schermerhorn, 1986; Baker et al., 1977). The erucic acid is extracted through a hydrolysis system, using steam and added glycerol. Erucic acid and other acids are removed with the glycerol (Robbelen et al., 1989).

Distillation

Distillation involves the separation of solvent and oil. This usually is achieved by conventional distillation methods. Most of the solvent is recovered for repeated use, which helps control the costs of extraction. However, distillation and recovery of the solvent generally involve large energy requirements. Consequently, the operating objective must be to concentrate as much oil as possible in the least practical amount of solvent.

Degumming

The hot oil must be cooled to 82° and then immediately passed through a degumming process, where it is thoroughly mixed with 1-2 percent of hot condensed water. Sometimes, phosphoric acid is added to help the gum precipitate and coagulate. Afterwards, the gum is removed with a centrifugation and filtration system (Appelqvist and Ohlson, 1972).

Next, the oil-water mixture is sprayed in a vacuum chamber at about 105° C. The water turns into vapor and escapes, whereas the oil is drawn off at the bottom, cooled, and pumped to storage.

Solvent Removal from Meal

The residual solvent in the meal as it leaves the extractor is usually about 25 to 35 percent by weight. A toaster heats the meal-solvent product and vaporizes the solvent from the meal at atmospheric pressure (Appelqvist and Ohlson, 1972). The residual level of hexane in the meal is then about 300 to 1,200 ppm.

The targeted level of oil remaining in the cake is about 1 percent. Although this is readily attainable for soybean meal, it is almost impossible to achieve for rapeseed, so a higher proportion of oil can be expected in the meal.

Crambe Specifications

Since no equipment has been specifically developed for processing crambe seed (Fig. 9), precautions are necessary to adequately handle it. Crambe seed seldom exceeds 6 to 8 percent moisture, but foreign material (leaf and stem debris and other seeds) can increase this to

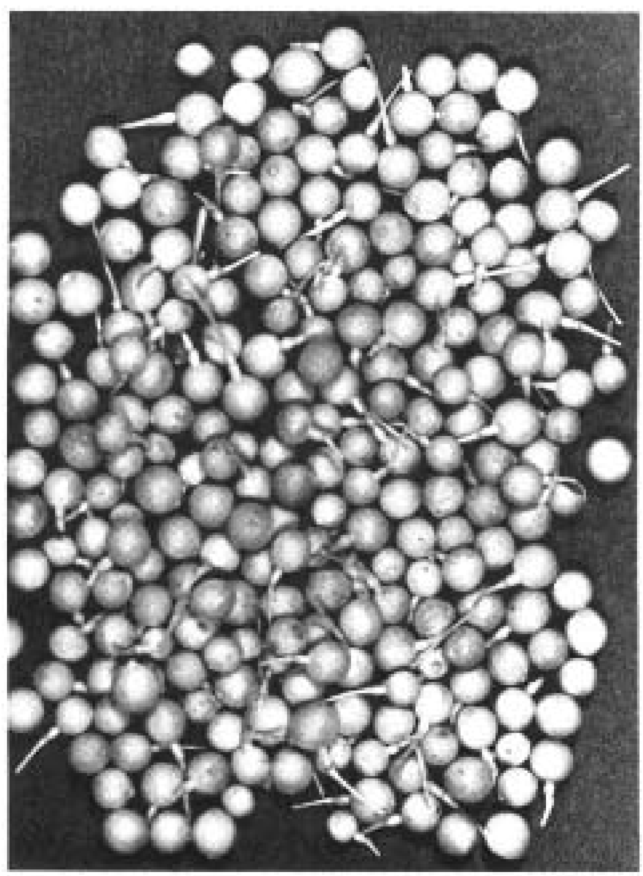

Figure 9. Crambe seed

20 percent. For this reason, the mill must have a drying facility and proper storage conditions available.

The following specifications are from a study by Carlson et al. (1985) for a commercial handling facility. For preconditioning seed, a stack cooker with four to six kettles is desirable. Seed entering the first kettle should be heated rapidly to 93° C. The moisture then should be equilibrated at 10 percent (or more) by uniformly distributing the steam. Subsequent kettles should maintain moisture and temperature for 15 to 20 min., so that the thioglucosidase is completely inactivated. The last kettle should dry and cool the seed before it is fed to the expellers or flaking rolls. The flake thickness should be 0.635 cm. If flakes are to be prepared for straight solvent extraction, flaking rolls should be set for 2.5 to 3.8 mm thickness.

Extractor design appears to be of secondary importance for oil removal from crambe flakes or pressed flakes. The technical specifications are solvent/meal ratio of 2/1; residual oil in the cake, 1 to 2 percent; time of solvent extraction, 60 minutes; and operating temperature, 57° to 63° C.

No modifications are required for solvent removal from the meal. It can be done in the lower kettles, with steam injection to facilitate the solvent extraction. The emerging meal should have about 8 to 10 percent moisture. It is ground before being conveyed to the storage facility.

Ideally, the finished meal has no thioglucosidase activity, but a high glucosinolate level (about 70 percent of the original value). More than 50 percent of the meal nitrogen is extractable, and it has a high lysine content, a low oil level, and little or no nitrile (Carlson et al., 1985; Carlson and Tookey, 1983; Baker et al., 1977; Van Etten et al., 1977).

The results of the study described above demonstrate the feasibility of processing crambe in existing facilities that were not originally designed for this purpose. Other studies have reported a great interest in using existing plants to control processing costs (Van Dyne et al.[4]).

Summary

Equipment is needed to efficiently remove rapeseed hulls. The high moisture content of crambe seed requires a drying facility. Otherwise, the technical feasibility of crushing HEA oilseed appears to be similar to requirements for crushing other oilseeds. High erucic acid oilseed can be crushed readily in existing facilities that usually crush soybean or sunflower seeds, with regular equipment. However, the operation of switching from HEA to regular vegetable oilseed requires the plant to be stopped for a while, so the equipment can be cleaned, adjusted, and prepared.

COST OF PROCESSING

Only a few studies have been conducted to estimate costs of vegetable oil processing. Costs for processing HEA oil from rapeseed or crambe are comparable to those determined for other vegetable oilseeds (Blase, 1988).

The different costs provided in this section are from a report originally prepared for the Department of Energy (Scheithauer and Dripchak, 1988) and from a document presented at a recent meeting of the American Institute of Chemical Engineers (Van Dyne et al.[4]). According to the latter, the cheapest way of processing HEA oil is to use existing facilities. The seed could be crushed in the slack season, when those plants are otherwise shut down or operating at less than full capacity.

Significant, excess crushing capacity currently exists in the oilseed industry (soybean, sunflower, cotton, and peanut). As noted by Scheithauer and Dripchak (1988), soybean crushing plants are working at 66 percent capacity and the average, vegetable oilseed industry at 75 percent capacity. Thus, the possibility of crushing crambe and rapeseed in existing facilities seems to be economically and technically a good solution.

Costs of processing different vegetable oilseed will be compared with those for processing rapeseed and crambe, on the basis of size of the plant. Size is given by the daily crushing capacity or daily crushing-refining capacity. The costs of processing in new and specially designed facilities also will be considered and compared with those obtained when using existing facilities. Several factors affecting variations of costs will be discussed.

Types of Extraction Processes

According to Scheithauer and Dripchak's report (1988), the type of extraction process used is a major factor influencing costs.

The mechanical process consists of simply pressing the seed to extract as much oil as possible. Usually, this process is used only in smaller plants that are much more labor- and energy-intensive. It requires higher maintenance costs and, thus, higher per unit costs of operation.

The prepress solvent extraction method usually is used with oilseed containing more than 25 percent oil (sunflower and flaxseed). The advantage of this process is that the equipment needed for a given throughput of product is greatly reduced, thus, giving lower fixed costs per unit. Therefore, this method is the least expensive. Furthermore, most of the plants are large and realize economies-of-scale advantages. Many of the plants operate at full capacity throughout the year, distributing the fixed costs over more units.

Estimated Costs

Estimating costs of rapeseed oil processing should include several factors, such as, site and region where the seed is processed; economies of size; type of oil extraction process; and oil content of the seed.

Total costs/gallon of rapeseed oil range from $.30 to $1.35. The lowest cost mentioned was achieved using a prepress solvent extraction process and the largest plant size. Costs for crambe should be slightly higher because of a lower oil content.

Different sized processing plants and types of equipment can be compared (data from Scheithauer and Dripchak, 1988). Most costs are based on operating 24 hours a day and 300 days a year. Cost data for retrofitted facilities are based on an extended operation period of 60 days per year to process rapeseed.

A new facility processing 440 and 660 tons per day and utilizing the prepress solvent method is considered the most expensive, at $.35 and .31 per gallon, respectively.

A retrofitted plant processing 495 tons per day and using a prepress solvent method usually crushes cottonseed and peanuts. No additional equipment is needed to switch to rapeseed or crambe. There is only a need to adjust existing equipment and to clean the plant before processing the new seeds. The low unit cost of processing ($.18/gallon) includes only variable costs.

A retrofitted plant processing 1,716 tons per day using a solvent extraction method was originally designed to process cottonseed and sunflower seed. It is not as efficient when crushing rapeseed or crambe. In this case, additional equipment estimated at $2.2 million is required to crush those seeds. The $.22/gallon unit cost includes the additional capital costs required and the lower extraction efficiency.

Scheithauer and Dripchak's report (1988) showed that costs of processing oilseed crops ranged from a high of $2.45/gallon for sunflower oil using mechanical extraction in a small plant to a low of $.19/gallon for prepress-solvent extraction of flaxseed oil in the largest sized plant.

Rapeseed is among the less expensive oilseed crops to process, whereas soybean is among the more costly. This is due partly to the oil content, which is only about 18.7 percent for soybean and 44 percent for rapeseed. The oil content influences the cost of processing much more than the size of the plant. Crambe contains about 35 percent oil in its seed, making the processing costs approximately $.42/gallon.

Splitting of crude oil (separation of fatty acids from glycerol) usually is done in chemical plants separate from the crushing facilities. Performing crushing and splitting in one location would reduce transportation costs and, therefore, processing costs. The estimated values for erucic and other fatty acids from 1 pound of crude oil are $0.79 for crambe and $0.73 for rapeseed (Van Dyne et al., 1990).

Summary

The most economical way to use existing facilities is to crush HEA oilseed probably once a year, when regular oilseed crushing is in a slack season. The economic study indicates that crushing HEA oilseed can be profitable. Rapeseed and crambe are less expensive to process than soybeans, because of their higher oil content. Total costs per gallon for rapeseed oil can be as low as $.30.

UTILIZATION OF MEALS

By-products of the vegetable oil industry constitute an important source of protein for the animal feeding industry. Oilseed by-products have been used for this purpose for centuries. Reference has been made to rapeseed cultivation in ancient Sanskrit writings as early as 2000 to 1500 B.C. (Carlson and Tookey, 1983).

The problem stressed recently by nutritionists concerns glucosinolate, an antinutritional factor contained in members of Brassicaceae. This gives the plants their spicy flavor. Its effects on growth rate, goiter formation, and palatability are well known (Appelqvist and Ohlson, 1972).

Rapeseed Meal

Rapeseed meal (RSM) (Fig. 10) contains primarily protein (35 to 49 percent), followed by carbohydrates and crude fiber (Table 10). Moisture-free rapeseed will yield 55 to 60 percent RSM by weight and 40 to 45 percent oil. Rapeseed meal is somewhat lower in protein content than dehulled crambe meal (35 vs 40 percent). Crude fiber content of rapeseed meal is twice as high as that of crambe meal. Among the carbohydrates, sucrose is the most prevalent (Table 11). The mature seed contains very little starch, and most of the cellulose is in the hull.

Rapeseed hulls are fibrous, low in protein and other nutrients, and low in digestibility. The presence of hulls

Table 10. Composition of HEA, high glucosinolate and LEA, low glucosinolate rapeseed meals

Constituent	HEA-HG	LEA-LG
	–percent–	
Protein	35.0	38.0
Carbohydrate	15–16.5	–
Crude fiber	12.8	11.0
Moisture	8.7	7.6
Ash	6.4	–
Glucosinolates	2.7–7.9	0.2-0.5
Ether extract	1.8	3.8
Phenolic compounds	0.1	–

Data from Hougen and Stefansson, 1983

Table 11. Carbohydrate content of rapeseed meal

Carbohydrate	Percent Defatted Dry Matter
Sucrose	6.0
Stachyose	2.5
Raffinose	0.3
Fructose	0.2
Glucose	0.2
Digalactosylglycerol	0.1
Galactinol	0.1

Data from Bengtsson (1985)

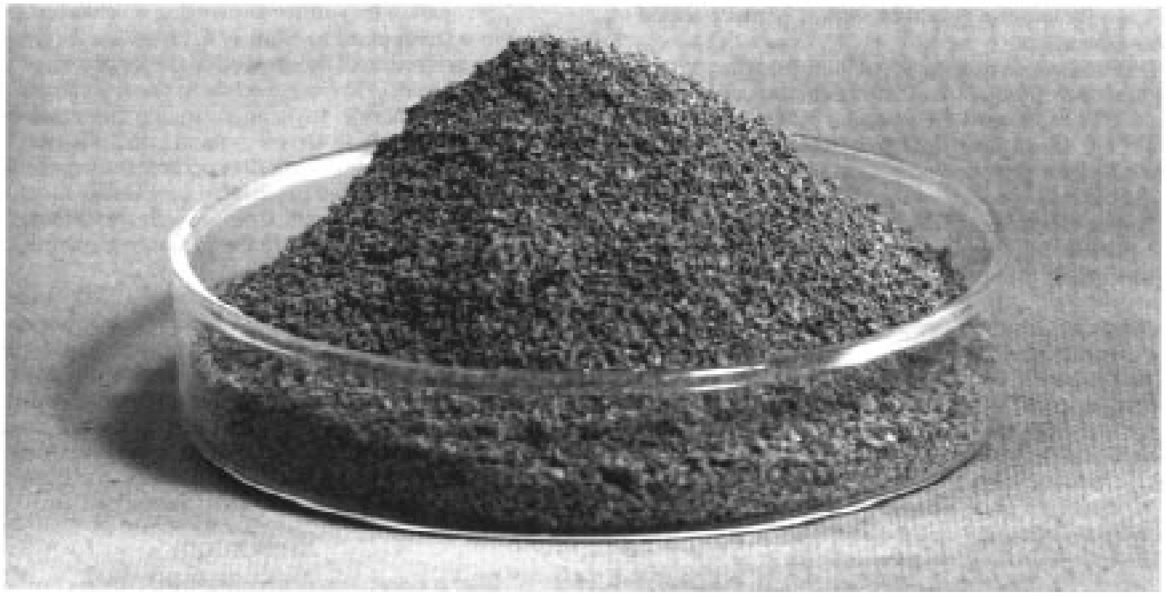

Figure 10. Rapeseed meal

makes 26 percent of the carbohydrates unavailable to animals. However, dehulling is not done routinely unless there is a use for the hulls. Researchers are breeding plants with thinner hulls that will interfere less with digestibility (Röbbelen et al., 1989).

Phytic acid and phytates occur in rapeseed. The presence of these compounds in animal rations has been proven to cause adverse effects, since they limit the bioavailability of zinc. However, the problem is easily overcome by zinc supplementation. This is certainly one reason why plant breeders have not yet tried to lower the proportion of phytic acid in rapeseed.

Rapeseed meal contains 1 to 1.5 percent sinapine, which is the choline ester of sinapic acid. This compound confers a bitter taste to the meal, which affects its palatability. Furthermore, it can cause a brownish tint to egg shells (Fenwick et al., 1984 a, b). This is a good commercial property in Europe, but is generally unacceptable to most consumers in the United States. So far, no toxic effect has been reported.

The inorganic constituents of RSM are reported in Table 12. The major strength for rapeseed and other members of the Brassicaceae is the high sulfur content. However, RSM is somewhat deficient in manganese. This may cause problems if RSM is the only protein complement fed to cattle grazing newly grown pastures. There is no problem if RSM is fed with soybean or other meals. RSM also can be supplemented with manganese.

Our knowledge is very limited concerning various vitamins, except for the four most important, which are generally present in feedstuffs. Rapeseed contains 168 mg/kg niacin, 17 mg/kg pantothenic acid, 3 mg/kg riboflavin, and 9 mg/kg thiamine (Appelqvist and Ohlson, 1972).

Detoxification

Concerning glucosinolates, the optimum conditions for processing rapeseed should avoid glucosinolate hydrolysis. The intact compound is much more easily removed than compounds resulting from hydrolysis. A treatment using tap water at 100° C and then dilute HCl at 0° C and dilute NaOH at room temperature has been proposed. Glucosinolates then are readily removed from the alkaline solution by gel filtration and by repeated washings. Subsequent feeding trials showed that this treatment was effective in the removal of glucosinolates (Lieden et al., 1980).

However, the methods tested so far have not been practical for use in large rapeseed-crushing plants. For this reason, plant breeders initiated a search for genetically controlled, low levels of glusocinolates in rapeseed. A

Table 12. Inorganic constituents in rapeseed meal

Constituent	Amount
Sulfur	0.7–1.8%
Potassium	1.3–1.6%
Phosphorus	1.1–1.2%
Calcium	0.7–1.1%
Magnesium	0.05–0.6%
Zinc	0.006–0.6%
Copper	5–700 ppm
Sodium	6–100 ppm
Selenium	80 ppm
Manganese	37 ppm
Boron	18–24 ppm
Iron	7 ppm

Data from Appelqvist and Ohlson, 1972

new variety, 'Indore,' is currently available. This variety has HEA and low glucosinolate, so it should not need any detoxification.

For phytic acid, the problem is less crucial. More than 64 percent of phytic acid can be extracted by distilled water at 0° C. An extraction in alkaline solution and gel filtration is possible and gives better results (100 percent removal), but the costs involved are greater than the increased value of the meal. Other efficient methods have been identified, but cost estimations for commercial use have not been made (Lieden et al., 1980).

Crambe Meal

Crambe seed is composed mainly of oil, a nitrogen-free extract, and protein. After the seed has been dehulled, the amount of oil increases to about 46 percent, and protein decreases to about 26 percent (Table 13).

The hulls contribute significantly to the fiber content of the whole seed. However, the seed can be dehulled easily to produce a higher protein, lower fiber meal.

Detoxification

Dehulled, defatted crambe meal (CM) contains from 8 to 10 percent glucosinolates (Table 13). More than 90 percent of the glucosinolates will be transformed naturally into epigoitrin. In the seed, epigoitrin is biologically separated from the glucosinolate hydrolyzing-enzyme system called thyoglucosidase. A reaction between epigoitrin and this enzyme may occur if the seed is crushed, if it germinates, or when the plant tissues are softened. Heat destroys the enzyme. However, since enzyme activity is exhibited by some intestinal bacteria (Oginsky et al., 1965; Tani et al., 1974), ingested epigoitrin still could be hydrolyzed into aglucone products in the digestive tract of animals fed raw crambe seed or meal. The feed value of crambe will depend partly on the relative toxicity of intact epigoitrin and on the levels of aglucone products present. These products are toxic and have a bitter taste that makes the meal unpalatable.

Three main detoxifying methods have been tested and used. One method is based on the addition of chemicals that produce a meal still containing aglucone products. Trials conducted on monogastric animals have revealed that growth rates were reduced by 20 to 30 percent and thyroid, liver, and kidneys were often enlarged relative to those of control animals (Carlson and Tookey, 1983).

A second method (conventional processing), based on thermal inactivation of the enzyme by using microwave energy, has not given good results in trials. Toxicity was not removed.

A third method is water extraction. This process consists of chemical or conventional inactivation of thioglucosidase, followed by repeated water washings of the meal to extract nearly all of the glucosinolates (Mustakas et al., 1976). Results suggest that water-washed crambe meal could be used at reasonable levels (15 to 20 percent) in feeds for monogastric animals (Baker et al., 1977). However, there is an inevitable added cost that would have to be recovered in higher meal or oil prices. Some authors have suggested that extracted epigoitrin or its derivatives could be used as pesticides (Tookey et al., 1980).

The available lysine in meal is a good indicator of both nutritional quality and protein damage. Proteins are well known for being sensitive to heat (Mailard effect). Meal with lysine complements cereals, which are always deficient in this amino acid. The level of available lysine declined only from 5.1 to 4.6 percent with washing (Baker et al., 1977). Water washing of meal thus appears to be sufficient to remove glucosinolate and its derivatives, while conserving the integrity of most of the proteins and, hence, the quality of the product.

Another detoxification method has been tested by K. J. Lessman[3]. The procedure involves irradiation of crambe seed with Cesium 137 and Cobalt 60 at levels up to 75 and 76 Mrd, respectively. A glucose test showed that endogenous thioglucosidase was no longer reactive with glucosinolates at levels of irradiation as low as 50.4 Mrd. Furthermore, the treatment increased the content of erucic acid in the oil. Other fatty acids were left relatively unaffected. Certain parameters still need to be specified. One of these is the optimum, effective level of irradiation for inactivation of the enzyme and/or destruction of glucosinolates. Another parameter is determination of the breakdown products and their effects on feed quality, using feeding trials. More studies should be conducted to determine the long-term effects of irradiation. However, the unavoidable ethical problem of irradiating feedstuffs arises and will have to be considered.

Table 13. Composition of crambe seed and meal

	With Hulls		Dehulled	
Constituent	Seed	Defatted Meal	Seed	Defatted Meal
		–percent–		
Oil	35.3	–	4.7	0.9
Protein	20.1	31.3	25.8	48.7
Crude fiber	14.3	22.1	3.6	6.7
Ash	4.8	7.4	4.5	8.6
Nitrogen-free extract	25.4	39.3	19.6	35.6
Glucosinolates	–	4.5–7	–	8–10

Data from Mustakas et al., 1965; Kirk et al., 1966; Baker et al., 1977; Carlson and Tookey, 1983

Animal Feeding Trials

The meal left after removal of HEA oil has been found to be an excellent protein source for animals. Many trials have been conducted during the past few years to estimate the nutritional value of crambe and rapeseed meals. The glucosinolates contained in the meal (up to 8 percent) cause many negative effects on growth rate and reproduction. These have been observed especially with high levels of feeding. Monogastric species are much more sensitive to the antinutritional factors than ruminants.

Growing conditions, cultivation methods, and oil removal processes affect the quality of the meal. They can influence the amino acid composition and myrosinase activity and, thereby, the release of split products from glucosinolates. The composition of meals also can be influenced widely by environmental factors, e.g., changing the level of nitrogen fertilization will affect the proportion of protein in the meal (Bengtsson, 1985).

Rapeseed Meal

To be acceptable as a feedstuff, rapeseed meal (RSM) should contain at least 32 percent protein and no more than 12 percent crude fiber after processing by mechanical extraction (Van Dyne et al., 1990).

The maximum level of RSM for poultry depended on the level of glucosinolates and the variety of rapeseed from which the meal was derived. With a high glucosinolate level, the maximum rate in the ration was 15 percent, but with a low glucosinolate level, RSM could provide up to 20 percent of the ration (Clandini and Roblee, 1977).

Poultry derive less metabolizable energy from RSM than do cattle or swine. However, when the meal is included in diets that meet energy requirements, excellent performance is obtained. Low-glucosinolate RSM is being used extensively in the production of broilers (Röbbelen et al., 1989).

Concerning egg production, iodine content in eggs has been reported in some trials (Clandini and Roblee, 1977; Sim et al., 1985). Iodine can concentrate up to harmful levels in eggs. Rapeseed meal ration fed to hens also tainted eggs with a fishy taste. This problem was due to trimethylamine. Thus, RSM is not recommended for feeding chickens that produce eggs.

Rapeseed meal had lower palatability for ruminants under 6 months of age than soybean or linseed meals, but only during the first 2 or 3 days on the diet. After that, no differences were observed and performances were comparable (Appelqvist and Ohlson, 1972).

Results from studies of growing and fattening ruminants are similar. Some palatability problems have occurred, but only at the beginning of the feeding period. Then the animals consumed their rations and gained weight at approximately the same rate as animals fed other oilseed meals (Whiting, 1965). Ruminants did not develop goiters when fed RSM, and no apparent toxic effects were observed in these animals.

A later study by Clandini and Roblee (1977) reported that the proportion of RSM in cattle rations should not exceed 20 percent. Heidker and Klopfenstein (1990) published the following results obtained with steers that were fed diets with RSM as 33, 67, or 100 percent of the protein source (replacing soybean meal). 1. There were no differences in average daily gain. 2. Feed efficiency was best for animals fed 100 percent RSM. 3. Carcass quality characteristics were comparable for all animals, except the percent of meat graded choice was greater as the amount of RSM was increased.

For dairy cattle, some palatability problems have been reported with RSM. However, as with beef cattle, the problems lasted only a few days, until the animals became adapted to the ration. Clandini and Roblee (1977) reported several contradictions in trials with dairy cows. Some authors indicated that up to 25 percent RSM can be used in cow rations. Other authors suggested that only 8 percent RSM in the ration affected milk fat production. Appelqvist and Ohlson (1972) proposed a RSM level of 10 percent, which seems to be reasonable.

The amino acid composition of protein was very important for monogastric animals tested. When the amino acid pattern of RSM was compared to the amino acid requirements for young pigs, it was found to be favorable. According to results of feeding experiments, swine were very sensitive to glucosinolates. The proportion of RSM depends on the age of the animal (Table 14). For young pigs, from 55 to 198 pounds liveweight, the highest recommended level is 10 percent. Comparative figures for poultry and cattle also are shown in Table 14.

Crambe Meal

The effect of crambe meal incorporated into poultry rations has been reported in a large number of studies. Baker et al. (1977) observed that chicks fed 20 percent conventional washed CM had a lower weight gain (14-16 percent) than those fed soybean meal. Feed efficiency ranged from 91 to 95 percent. When crambe was water washed, usually no thyroid or gizzard problems were reported. If not washed, serious troubles from the antinutritional factors were observed (Baker et al., 1977; Sim et al., 1985; Kramer et al., 1983).

The problem is somewhat different concerning egg production. The presence of sinapine in the meal taints brown-shelled eggs with a fishy taste. Therefore, the recommended level of CM is not more than 5 percent for hen rations (Kramer et al., 1983).

Incorporating CM into a swine ration has particularly bad effects on voluntary intake because of their very sensitive taste ability. Therefore, the inclusion of CM should be limited to 3 to 5 percent. If the ration has more than this amount, swine will eat less and performance will be less than desirable (Carlson and Tookey, 1983). However, crambe has a very well balanced pattern of essential amino acids.

The inclusion of some CM in swine rations should be considered as improving the quality of the ration, its balance in amino acids, and, therefore, its protein efficiency rate. Better protein utilization (because of a better balanced amino acid composition) should compensate for lower intake caused by lower palatability. The more a ration is unbalanced, the more the animal will increase intake to compensate for the deficient amino acids (Jarrige, 1978). Consequently, a decrease of voluntary intake could be partly due to a better balanced ration. The problem of lower voluntary intake of rations containing CM has been reported in many publications as being less important for cattle than for monogastric species (Appelqvist and Ohlson, 1972; Baker et al., 1977).

A trial conducted by Lambert et al. (1970) compared the performance of steers fed rations containing different proportions of CM for 196 days (Table 15). The most significant result was the decreasing daily intake when the amount of CM was increased. However, differences in feed efficiency were not significant, indicating that increasing the proportion of CM in the ration did not reduce its nutritional quality, even though palatability may have been lowered. By sorting its ration, an animal decreases daily feed consumption. This can be overcome by pelleting rations or blending CM and soybean meal.

Between 1972 and 1977, several long-term feeding studies (152-182 days) were conducted to obtain approval of crambe as a supplemental protein source in beef cattle rations as required by the Food and Drug Administration (Perry et al., 1983). In Experiment A (Table 16), CM replaced 1/3, 2/3, or all of the soybean meal in a high energy diet. Rate of gain and daily feed intake decreased with increasing levels of CM, but these differences were not significant, even when CM supplied all the protein in the diet. Furthermore, feed efficiency did not change.

In Experiment C (Table 16), the purpose was to estimate the effect of CM as it was progressively increased in three rations, which also increased in total crude protein

Table 14. Levels of rapeseed meals recommended in rations for various animals

Species	Production Phase	HEA-HG Rapeseed	HEA-LG Rapeseed
		–percent–	
Chickens	Starter, grower	15	20
	Layer, breeder	5	10
Turkeys	Starter, grower	10	20
	Breeder	10	10
Swine	55 lbs liveweight	–	4-5
	55-200 lbs liveweight	3	10
	Sows (pregestation, lactation)	–	3
Cattle	Young (6 mos)	20	20
	Growing and fattening	10	20
	Dairy cows	5	5-10

Data from Appelqvist and Ohlson, 1972; Clandini and Roblee, 1977; Kramer et al., 1983
HEA = high erucic acid, HG = high glucosinolates, LG = low glucosinolates

Table 15. Performance of cattle fed rations containing crambe meal (196 days)

Parameter	Corn Diet	Percent Protein from Crambe 33	67	100
Daily gain, lb	2.60	2.47	2.16	1.90
Gain as % of control	–	95.00	83.00	73.00
Daily feed, lb	19.80	19.80	18.30	13.20
Feed per lb of gain	7.63	8.00	8.50	7.00

Data from Lambert et al., 1970

Table 16. Crambe meal as a protein supplement for beef cattle

	Experiment A				Experiment C			
Parameter	Diet 1	Diet 2	Diet 3	Diet 4	Diet 1	Diet 2	Diet 3	Diet 4
Protein, %	10.3	10.3	10.3	10.3	9.0	9.6	10.3	11.0
Crambe meal, %	–	4.2	8.4	12.6	–	2.5	5.4	8.3
Soybean meal, %	7.5	5.0	2.5	–	–	–	–	–
Daily gain, kg	1.1	1.1	1.1	0.9	1.0	1.1	1.1	1.1
Daily feed, kg	8.3	8.0	7.5	7.4	7.8	7.9	8.0	7.9
Feed/Gain ratio	7.5	7.4	7.4	8.0	7.8	7.5	7.1	6.0

Data from Perry et al., 1983

content. Differences in feed efficiency were significant. The best result was obtained with 11 percent crude protein and 8.3 percent provided by crambe.

In another study, cattle were fed on rations containing 10 percent CM for up to 30 days. The purpose was to determine whether epigoitrin or aglucone products would appear in their fat, muscle, liver, or kidney tissues after slaughtering. None of these compounds was detected in body tissues by methods sensitive to 1 ppm (Van Etten et al., 1977).

The FDA has approved use of solvent-extracted crambe meal in beef finishing rations at a level up to 4.2 percent of total weight of the rations (Van Dyne et al., 1990).

Comparisons with Other Feeds

Nutritionists recommend avoiding a unique source of protein. Diversifying protein sources should lower the risk of deficiencies in any element. Neither rapeseed nor crambe meal can be considered as a main protein source for animals, especially monogastric species. However, both RSM and CM are well balanced in terms of amino acids, protein, and vitamins. Therefore, these meals can complement soybean meal used as the major source of protein in a ration.

Rapeseed meal contains less protein than soybean meal; 36.6 percent for HEA-HG or 38 percent for HEA-LG compared to 45 percent for soybean meal. Furthermore, RSM contains more crude fiber, 11 or 12 percent compared to 6 percent for soybean meal. However, the amino acid pattern of RSM compares favorably with that of soybean meal, considering the major, essential amino acids in terms of nutritional value for monogastric species and highly productive dairy cows (Table 17). Rapeseed meal contains the amino acids that are lacking in soybean meal, generally having a better content of sulfur-containing amino acids.

Many trials have been conducted to evaluate RSM as a substitute for soybean meal. Lower palatability of RSM has been observed for several animal species. However, in feeding trials with lambs, RSM produced an acceptable average daily gain of 0.72 lb compared to 0.85 with soybean meal (Schwulst, 1986).

In another trial, a ration with 3.3 lbs/day RSM was given to one set of cows, and a control group was given 2.6 lbs/day soybean meal. Although the palatability of RSM was lower, cows on that ration produced more milk, but milk fat was slightly lower. There was no significant difference in total fat production or in the taste of the milk between the two groups (Bengtsson, 1985).

In another trial conducted to estimate the effect of RSM rations fed to milk cows, Whiting (1965) concluded that RSM can be considered equivalent in nutritional value to linseed and soybean meals at levels up to 10 percent of the total dry matter of the ration.

The protein digestibility of RSM (83 to 86 percent) compares unfavorably with that of soybean meal (91 to 93 percent). However, the net protein utilization is higher (74 to 86 percent) than for soybean meal (63 to 65 percent) (Bengtsson, 1985).

Comparisons made on the basis of nutritional value indicate that RSM contains less energy and less available nitrogen than soybean meal. That makes RSM less valuable, as discussed above, so it should be considered as a complement to soybean meal not as a substitute (Jarrige, 1978).

Table 17. Amino acid composition of soybean and rapeseed meals

Amino acid	Soybean Meal	HEA-LG Rapeseed Meal
	–percent by weight–	
Glutamic acid	8.10	6.35
Aspartic acid	5.40	3.05
Leucine	3.37	2.65
Arginine	2.90	2.21
Lysine	2.80	2.21
Serine	2.25	1.67
Valine	2.25	1.94
Proline	2.20	2.66
Phenylalanine	2.16	1.52
Isoleucine	2.11	1.51
Glycine	2.07	1.89
Alanine	1.89	1.73
Threonine	1.71	1.71
Tyrosine	1.26	0.94
Histidine	1.08	1.03
Methionine	0.63	0.68
Tryptophane	0.54	0.44
Cystine	0.29	0.47

Data from Hougen and Stefansson, 1983

Compared with sunflower meal, RSM is either richer in energy or in available nitrogen. Proportionally, RSM is better adapted for meat production, because its UFV (available energy for meat production) value is superior to that of sunflower meal (Table 18).

Compared with linseed meal, RSM has less energy but is richer in available nitrogen. This makes RSM a better supplemental protein source than linseed meal for animal rations (Table 18).

Rapeseed and peanut meals are comparable for both energy and available nitrogen (Table 18).

Rapeseed meal contains more energy than cottonseed meal (except for the dehulled expeller cottonseed meal), whereas cottonseed meal contains more available nitrogen (Table 18).

Palmseed meal, coconutseed meal, and sesame seed meal all have more energy than RSM, but contain less available, digestible nitrogen (Table 18).

Thus, RSM usually has a higher nutritional value than its direct substitutes. However, the difference is not very important and, thus, would not justify a much higher cost to use RSM.

Cost Comparisons

The values given for August, 1988 (Table 19) were influenced by the drought that was affecting the United States. Soybean meal prices increased considerably because of the poor prospect for the coming 1988 harvest.

Average cost, per 1 percent of protein, ranged from $3.57 for RSM up to $5.40 for sunflower meal. This cost differential was due to the higher oil content of rapeseed. Furthermore, industrial utilization and quality of HEA oil give it a higher value on the market. The costs of processing RSM are less than those of processing soybean (edible oil).

Rapeseed meal is a "low value to weight" commodity and, therefore, very freight sensitive. The total meal demand in Kansas was estimated at 910,000 tons/year and was easily affected by price competition. As well as being a major crop-producing state, Kansas is also a major meat producer. A discount of $20/ton for RSM (compared to soybean meal) on a protein equivalent basis would be enough to compete favorably. This was based on an estimate of feeding 918,000 cattle (about 20 percent of total) and 118,000 swine (about 3 percent of total for the state).

Summary

Evidence indicates no major obstacles to the utilization of crambe or rapeseed meals to feed either cattle or monogastric animals, when used within a certain range. Crambe and RSM are complementary to soybean meal, because they supplement certain amino acids not contained in soybeans. The problem of glucosinolate and its antinutritional effects has not been solved completely (especially for crambe meal). The water washing system is one solution, but further studies should be conducted on a commercial scale. This problem leads to certain restrictions in daily rations for animal feeding. However, if the quality of the meal is improved, Kansas could be an ideal market for RSM. Thus, an outlet for meal shouldn't be a barrier to developing production of industrial, HEA oil.

Table 18. Nutritional values of various oilseed meals

	Energy Value		Nitrogen Value	
Type of Meal	UFL	UFV	PDIN	PDIE
	–for 100 g/kg dry matter–			
Coconutseed				
expeller	1.11	1.80	183	193
deoiler	0.96	0.92	185	195
Cottonseed				
with hull-expeller	0.66	0.54	175	153
½ dehulled-expeller	0.87	0.78	280	230
dehulled-expeller	1.00	0.93	326	270
½ dehulled-deoiled	0.78	0.68	275	226
dehulled-deoiled	0.88	0.81	324	267
Linseed				
expeller	1.07	1.02	219	125
deoiled	0.96	0.91	232	129
Palmseed				
deoiled	1.02	0.98	166	181
Peanut				
with hull-expeller	0.92	0.84	253	140
with hull-deoiled	0.72	0.62	223	124
dehulled-expeller	1.13	1.09	337	185
dehulled-deoiled	1.06	1.01	343	187
Rapeseed				
expeller	0.99	0.92	248	187
deoiled	0.94	0.87	268	198
Sesameseed				
expeller	1.15	1.11	322	229
Soybean				
42-44%	1.17	1.15	347	261
48-50%	1.20	1.19	385	285
Sunflowerseed				
½ dehulled-expeller	0.86	0.76	249	151
dehulled-expeller	0.99	0.91	293	183
dehulled-deoiled	0.81	0.72	265	158

Data from Jarrige. 1978
UFL = available energy for milk production
UFV = available energy for meat production
PDIN = available nitrogen allowed by the fermentable nitrogen in the rumen
PDIE = available energy allowed by the fermentable nitrogen in the rumen

Table 19. Costs of oilseed meals used in animal rations

Type of Meal	Price in August, 1988
	–$/ton–
Cottonseed	
expeller	205
deoiled	209
Linseed	250
Peanut	200
Rapeseed 35%	125
Soybean	
44%	264
48%	283
Sunflower	
28%	125
30%	162

Data from Anonymous, 1988a; C. Klopfenstein (personal communication, 1988)

HIGH ERUCIC ACID OILS

Oil is the major economic product of rapeseed and crambe. Industrial uses for HEA oil are being developed in the United States. A few decades ago, fats and oils provided light and heat for a significant percentage of the population of many countries. The rising costs of petroleum and gas products allowed for direct competition from vegetable oils. The recent possibility of shortages of nonrenewable energy sources, such as petroleum, have raised interest in developing substitutes from vegetable oils. Most of the current or potential applications of HEA oil are met by a petroleum product or by-product.

To enter the petroleum product market, vegetable oil producers must provide industrialists with 1. scientifically proven, better characteristics of their product, 2. a price comparable to that of the original product, and 3. a continued, reliable supply of vegetable oil.

Composition of HEA Oils

The oil extracted from rapeseed or crambe can have HEA or LEA content. Rapeseed contains more oil than crambe (43 vs. 36 percent), but a lower proportion of each gallon is comprised of HEA oil (50 vs. 57 percent) (Kramer et al., 1983; Appelqvist and Ohlson, 1972).

Rapeseed and crambe oils consist mainly of triglycerides, with smaller amounts of monoglycerides and diglycerides; phospholipids, galactolipids, and sulpholipids; waxes; sterols and sterol esters; free fatty acids; hydrocarbons; carotenoids; alcohols; triterpenes; chlorophylls; tocopherols, and metal ions. The gross composition of LEA oil included 95.5 percent nonpolar lipids and 4.5 percent polar lipids. A sample of rapeseed oil with medium to high EA content had a very similar composition (Princen and Rothfus, 1984).

Fatty Acids

Composition of fatty acids is of great interest because most of them or their breakdown products can be used for industrial purposes. It is the fatty acid content that gives rapeseed and crambe oils their higher value. A fatty acid is a saturated, organic acid with one carboxyl group (COOH).

The major proportion of fatty acids in oilseeds occur in esters, such as triglycerides, phospholipids, and sterol esters. An ester is a compound formed by reaction between an acid and an alcohol. The intact seed contains only negligible amounts of free, unesterified fatty acids. When the seed is crushed during processing or damaged by mechanical means (during storage), certain hydrolyzing enzymes already present in the intact seed (like lipase), come in contact with lipids (fats) and gradually cause a release of free fatty acids. Small amounts of free fatty acids (usually considerably less than 0.1 percent, depending on the processing and refining conditions) occur in processed oil.

Fatty acid composition of the seed usually is reported as the total fatty acids obtained by hydrolysis of the oil, even if the content of triglycerides differs from that of the phospholipids and other esters (Appelqvist and Ohlson, 1972). The proportions of major fatty acids may vary by type of rapeseed or crambe (Table 20).

High erucic acid oils have characteristic long-chain fatty acids (including erucic) that may constitute more than 50 percent of the total. In LEA oils, these nearly disappear, and other acids (oleic and linoleic) correspondingly increase. Greater content of linoleic acid improves the nutritional quality of rapeseed products, whereas

Table 20. Fatty acid composition of oil from various types of rapeseed and crambe

	Fatty Acid					
Species	Palmitic	Oleic	Linoleic	Linolenic	Eicosenoic	Erucic
			–percent–			
HEA Oil						
Brassica campestris						
Winter turnip rape	2-3	14-16	13-17	8-12	8-10	42-46
Summer turnip rape	2-3	17-34	14-18	9-11	10-12	24-40
B. napus						
Winter rape	3-4	8-14	11-15	6-11	6-10	40-45
Summer rape	3-4	12-23	12-16	5-10	9-14	41-47
B. juncea	2-4	7-22	12-24	10-15	6-14	18-49
Crambe abyssinica	–	17	9	6	5	55
LEA Oil						
B. campestris						
Summer turnip rape	4-7	48-55	27-31	10-14	0-1	0-1
B. napus						
Winter rape	4-5	40-48	15-25	10-15	3-19	3-11
Summer rape	5	52-55	24-31	10-13	0-2	0-1

Data from Appelqvist and Ohlson, 1972; Kramer et al., 1983; Princen and Rothfus, 1984 teristics (Röbbelen et al., 1989). Several minor acid components have been identified, but their concentrations do not differ appreciably in HEA and LEA oils obtained from seed of either *B. napus* or *B. campestris.*

Triglycerides

The major constituents of HEA oil are triglycerides (esters of glycerol containing three ester groups). The more unsaturated fatty acids are secondary. In fact, rapeseed oil contains very small amounts of monoglycerides and diglycerides (1.2 percent and a trace, respectively) (Appelqvist and Ohlson, 1972).

Phospholipids

In a phospholipid, phosphoric acid as well as a fatty acid are combined in an ester with glycerol. The phospholipids and other polar lipids constitute 1.8 to 4.5 percent of HEA oil. Values as low as 0.5 to 1 percent have been reported (Appelqvist and Ohlson, 1972) but possibly refer to the analysis of industrially refined oils. Some of the components identified include phosphatidyl choline, phosphatidyl ethanolamine, phosphatidyl inositol, monogalactosyl, and digalactosyl.

Waxes

Waxes are found in the epicuticular lipids of the seed. They contain hydrocarbons, wax esters, aldehydes, primary and secondary alcohols, and hydroketones (Hougen and Stefansson, 1983). The waxes are very useful because of their stable characteristics. They differ from fats in being less greasy, harder, and more brittle. As reported by Nieschlag and Wolff (1971), waxes extracted from crambe oil have about the same melting point as beeswax (62° to 65° C), but are much harder (Pattison, 1968; Humko, 1964).

Nonsaponifiable Matter

The nonsaponifiable portion of rapeseed or crambe oil is composed of 64 percent sterols, 9 percent triterpenoid alcohols, 9 percent other hydrocarbons, 7 percent aliphatic alcohols, and 4 percent squalene (Appelqvist and Ohlson, 1972). These compounds are not hydrolyzed by alkalis to form a soap and glycerol.

Sterols

Sterols are solid alcohols containing a 17-carbon, four-ring system. The total sterols of rapeseed, including the free sterols and those combined in esters, glucosides, and esterified glucosides, reportedly constitute 0.5 to 3.9 percent of the oil (Hougen and Stefansson, 1983). This sterol fraction is comprised of 45 to 60 percent sistosterols, 29 to 43 percent campesterols, 7 to 12 percent brassicasterol, 0.2 to 0.8 percent cholesterol, and one to six percent other compounds. No differences in this pattern were observed among several cultivars studies (Appelqvist and Ohlson, 1972). Most of these sterols (particularly brassicasterol) can provide acids of high quality for industrial purposes (plastics, polyvinylchloride, perfume, etc.) (Nieschlag and Wolff, 1971).

Hydrocarbons

These are organic compounds containing only carbon and hydrogen (like acetylene or benzene). The hydrocarbon portion of rapeseed oil was separated into 36 subfractions (Appelqvist and Ohlson, 1972). The typical composition of each subfraction has been reported as being specific to each cultivar studied.

Carotenoids

These are yellow to reddish pigments. The carotenoid fraction of rapeseed oil contains lutein, neolutein A, neolutein B, and beta-carotene (Appelqvist and Ohlson, 1972).

Triterpenoids

These are hydrocarbons with three units, occurring in essential oils and resins. The triterpenoid fraction of rapeseed or crambe oil is the most complex of all studied and seems well suited for identification of unknown vegetable oils (Hougen and Stefansson, 1983). At least 13 components have been detected, and the major ones have been identified as beta-amyrin, cycloasterol, and 24 methylcycloasterol (Appelqvist and Ohlson, 1972).

Chlorophyll

Chlorophyll (the green pigment of plants) in rapeseed oil amounts to 14 to 35 ppm. In Sweden, farmers' crops are analyzed for chlorophyll content as a factor in the payment system for the seed. The maximum level for top quality seed is 30 ppm (Appelqvist and Ohlson, 1972).

Tocopherols

Two major types of tocopherols occur in rapeseed oil. They are fat-soluble, oily, phenol-like compounds. Their content in the oil varies from about 600 to 911 ppm (Hougen and Stefansson, 1983). For comparison, the range of tocopherols in other vegetable oils is 1170 ppm for corn, 1140 ppm for soybean, 730 ppm for sunflower, and 240 ppm for peanut (Princen and Rothfus, 1983). Reported losses of tocopherols during processing of the oil vary between 15 and 75 percent, with an average around 25 percent (Appelqvist and Ohlson, 1972).

Metals

Heavy metal ions found in vegetable oils are mainly associated with the phospholipids. The contents can vary considerably, depending on the processing conditions. Iron particularly may be dissolved from processing equipment. The few studies conducted to estimate the final content of metals in oil after processing are reviewed by Appelqvist and Ohlson (1972) and Hougen and Stefansson (1983).

Sulfur

Trace amounts of certain sulfur compounds occur in rapeseed oil, originating from the sulfur-containing glucosinolates in the seed. The total sulfur content was reported as 19 to 25 ppm in crude rapeseed oil and 1 ppm in refined and deodorized oil from high-glucosinolate varieties. The oil from low-glucosinolate varieties may contain less sulfur. However, crushing conditions may be more important than seed glucosinolate levels in determining the sulfur content of the oil (Hougen and Stefansson, 1983).

Industrial Uses of HEA Oils

Specific uses of rapeseed and crambe oils are based on their content of long-chain molecules or molecules with double bonds. Oils high in erucic acid have special attributes that make them useful in manufacturing. These attributes include high smoke and flash points, oiliness and stability at high temperatures, ability to remain fluid at low temperatures, and durability (USDA, 1989).

Oil used for industrial purposes usually is refined. Certain modifications in properties also can be achieved. A process called blowing has long been practiced to increase viscosity and involves passing a stream of air through the heated oil (Appelqvist and Ohlson, 1972). A blown rapeseed oil is quite soluble in paraffins but has low solubility in alcohol.

This section gives an overview of current and potential utilizations of HEA oil.

Rubber Additives

Factice originally was introduced as a rubber substitute, but is now frequently compounded with rubber. It is used widely in the rubber industry to decrease effects of aging and changes in shape. The technical process consists of a reaction between rapeseed oil and sulfur that yields a polymer, similar to the vulcanization process of rubber.

Vulcanized vegetable oils also are used widely for blending with natural and synthetic rubber in rather high proportions to help in processing and to give soft, highly elastic products that are more resistant to light and ozone. A vulcanized product from crambe oil has been evaluated commercially and found to be comparable to or slightly better than that made from rapeseed oil (Nieschlag and Wolff, 1971; Ohlson, 1983).

There are two varieties of factice, white and brown. White factice is prepared by reacting a relatively saturated oil (rapeseed or crambe) with liquid sulfur monochloride. The reaction takes place easily at cold temperatures and is quite complex. White factice is light colored, compressible, and more or less crumbly. An important use of this material is in the manufacture of gum erasers, to which it confers the necessary degree of friability (Appelqvist and Ohlson, 1972; Morton, 1963; Miwa and Wolff, 1963).

The first step in making brown factice is blowing a drying oil until it is thickened. This operation is followed by a reaction with about 5 to 30 percent sulphur in a closed vessel. The mixture is stirred at a temperature of 120 to 175° C for 1-2 hours. The physical properties of brown factice vary with percent of sulphur employed, processing temperature, and reaction time. The consistency varies from dark, viscous, and semisolid to hard and solid, but relatively fragile. The desired characteristics depend upon the final utilization. Brown factice has been used not only as a rubber extender but also to modify the properties of drying-oil products such as varnishes and linoleum (Nieschlag and Wolff, 1971).

Factice-like products with excellent flame-proof properties also have been prepared by polymerizing rapeseed oil and treating the product with phosphorous halide. These materials can be used as additives for rubber, lacquers, varnishes, plastics, adhesives, and lubricants. The addition of rapeseed-oil factice instead of sulphur in elastic packing materials has been shown to produce a material with a lower tendency to stickiness.[5]

Plastics

Epoxides of fatty acid triglycerides are used as plasticizers and stabilizers in polyvinylchloride (PVC), copolymers of PVC, and chlorinated rubbers (Appelqvist and Ohlson, 1972). Normally, the amount of epoxy plasticizer used is 5 to 10 parts per 100 parts of resin for stabilizing and 15 to 60 parts as a softener. These plasticizers reduce the effects of heat and light.

Erucamide (made from erucic acid) is especially recommended where high temperatures are involved because of its lower volatility. It is the preferred amide for use with polypropylene, even though it currently costs twice as much as oleamide (from oleic acid). Erucamide also is considered one of the best additives for extruded polyethylene and propylene film (Appelqvist and Ohlson, 1972). One of the most desirable characteristics of erucamide is its antistatic property, for which oleamide is the major competitor.

Several N, N-di-substituted amides of erucic acid and mixed crambe fatty acids have been prepared. These amides are effective external plasticizers for PVC-acetate copolymer (Mod et al., 1969). All but one of the erucic acid derivatives were compatible with the PVCA copolymer and exhibited good performance at low temperatures.

Various other di-esters of brassylic acid (a derivative of erucic acid), with alkyl parts ranging in size from methyl to decyl, also have been incorporated into PVC and evaluated as plasticizers that are excellent in low temperature conditions, giving the product a light stability (Nieschlag et al., 1964; Ohlson, 1983). Di-cyclohexyl brassylate has properties very similar to those of bis-3-ethylhexyl pthalate, the most widely used plasticizer in moderate temperature applications (Nieschlag and Wolff, 1971; Pryde and Carlson, 1985; Carlson et al., 1977). The commercial availability of brassylic acid should expand the range of uses for this important class of compounds.

Pelargonic acid (a coproduct of brassylic acid production) also has been reported to have applications for plasticizers and alkyd resins. This usually is esterified with polyfunctional alcohols. The ester has properties required in superior vinyl and synthetic rubber plasticizers (Appelqvist and Ohlson, 1972).

[5] Kirch, W. and W. Glander. 1957. German Patent No. 1,007,056.

Nylons

Nylon products represent tremendous potential for using HEA oil. A great deal of research has been focused on this possible application. So far, all nylons have been manufactured from petroleum sources. The petroleum base offers a long hydrocarbon chain, on which nitrogen atoms are added to form the basic frame of this modern fiber.

Two types of nylons have been made successfully from vegetable oils: nylon 13 and nylon 13-13. The latter has been widely studied, whereas the former is still in the research stage.

Nylon 13-13 is made from brassylic acid, which, in turn, is made from 1,13-aminotridecanocic acid. This has been synthesized from several materials that were not readily available. In 1969, Green and coworkers reported the production of 1,13-aminotridecanoic acid from erucic acid, methyl erucate, or eruconitrile.

The processes for production of nylon 13-13 were developed by the Southern Research Institute under contract to the USDA. Synthesis of nylon 13-13 is remarkably simple when compared to the reactions required to produce nylon 11 or nylon 12 (Nieschlag and Wolff, 1971). First, brassylic acid is reacted with ammonia under dehydrating conditions to give brassylic acid dinitrile, which, in turn, is converted into the diamine by catalytic hydrogenation (Anonymous, 1970; Nieschlag et al., 1977). Diamine and diacid monomers then are combined in stoichiometric proportions to form nylon salt, which then is converted readily to the polyamide by melt polymerization.

Carlson et al. (1977) reported production of brassylic acid in a small-scale plant. From crambe oil, they produced a yield of 72 to 86 percent brassylic acid, with 99 percent purity, and pelargonic acid as a coproduct. Nieschlag et al., (1977) reported the economical production on nylon 13-13 from crambe oil. They predicted that yield in a facility handling 5,000 metric tons/year would be 83 kg molten polymer per 100 kg of crude brassylic acid. A report by Princen and Rothfus (1984) mentioned that nylon 13-13 obtained from crambe oil was of a better quality than that obtained from rapeseed oil.

Not much information is available concerning nylon 13. The process for making it requires the cleavage of erucic acid at its double bond position by ozonolysis, followed by reductive amination to the omega acid, which is then polymerized by amine condensation (Appelqvist and Ohlson, 1972). Eruconitrile can be converted to primary behenyl acid through catalytic hydrogenation. In a preliminary study, eruconitrile has served as an intermediate in the production of nylon 13 (Green et al., 1969).

The technical advantages of nylons 13 and 13-13 are noteworthy, including tensile strength, percent elongation at break, and impact strength (Appelqvist and Ohlson, 1972; Nieschlag and Wolff, 1971; Kestler, 1968). The basic difference between these nylons and commonly available nylons is the former's content of repeating monomer units with longer polymethylene chains.

One consequence of this structure is a moderate melting point, which results in easier fabrication of these polymers for use in molding, extrusion, adhesive, and fluidized bed coating. When applied as a fluidized bed coating, nylon 13-13 forms a bond with the metal that is stronger than the cohesive strength of the nylon itself. The low melting point of nylon 13 (180° C) allows it to be treated at lower temperatures than conventional nylons, and this is a great gain. Both nylon 13 and nylon 13-13 should be easier to mold or extrude to form rods, filaments, and films (Appelqvist and Ohlson, 1972).

Because of its low volatility, nylon 13-13 can be injection-molded without the use of excessive temperature, pressure, or dwell times. Thus, pressure during initial stages of polymerization is no longer necessary (Nieschlag and Wolff, 1971; Ohlson, 1983).

Another major, technical advantage in the low water-absorption value for these new nylons, e.g., 0.42 percent at 30 percent relative humidity (Appelqvist and Ohlson, 1972). The low moisture characteristic provides excellent electrical properties and dimensional stability (Nieschlag and Wolff, 1971). Nylons 13 and 13-13 resist water absorption better than nylons 6 and 66 (the most common, commercially available nylons). This feature also contributes to a lower mold shrinkage, good flow properties for molding applications, and excellent resistance to attack by chemicals (Princen and Rothfus, 1984).

The economic information is less promising. The major handicap of rapeseed and crambe oils is their cost. It should be at least half of the current value in order to be competitive with petroleum products. Research is still being conducted to decrease the costs involved. A European company (BASF) may have developed a new industrial process for making nylon 13-13. This new process could be more efficient, less costly, and economically advantageous (M.G. Blase, personal communication, 1988).

Several industries are interested in the exceptional properties of nylon 13-13 (especially the automobile industry but also producers of electrical insulation and fishing line) (USDA, 1989). This outlet for crambe and rapeseed oils should be thoroughly examined, because it could represent tremendous amounts of oil consumption per year.

Coatings

The coating industry includes a very wide range of products for which either rapeseed or crambe oil can be a raw material, as a source of erucic acid or derived fatty acid. Manufacture of coating products uses millions of tons of raw materials every year. Although the proportion of vegetable oil is only 22 percent of total raw material, this still represents a substantial quantity (91,000 metric tons in 1982). Some vegetable oils also are included in alkyd, epoxy ester, urethane, and polyester resins, but the quantity is difficult to estimate. For example, alkyd ranges from oil-free up to 65 percent oil base, depending on the end use (Fulmer, 1985). Also vegetable oils include not only rapeseed and crambe, but soybean, sunflower, cottonseed oils, and others.

The high content of erucic acid in crambe and rapeseed oils is the characteristic especially needed for some coating applications. However, the price of HEA oil is near $0.60/pound, compared to $0.25 to 0.35/pound for other vegetables oils. This cost leads industrialists to use HEA oil only when it's strictly needed for specific properties.

Unfortunately, the coating field is not expected to increase much for the next 5 years (annual growth rate about 2 to 3 percent) (Fulmer, 1985). However, alkyd resins continue to be a major ingredient in coatings for specific uses, which provide a small but guaranteed outlet for HEA oils.

Slip Agent. A major use of HEA oil, after conversion to erucamide, is as a slip agent in the manufacture of plastics. It prevents individual sheets of plastic from sticking together. Approximately 20 million pounds of HEA are being used for this market, and more than 80 percent is imported. An American company recently has started to develop a domestic supply (USDA, 1989).

Film Forming. The coating industry now uses perhaps a few hundred million pounds of seed oils for film forming. Pelargonic acid also is used as a vinyl stabilizer in films. The major barrier for development of rapeseed or crambe oil in this area is the higher price. The ability of erucic acid to cling to metal surfaces even in humid conditions is indispensable only in a few applications, for which it is worth the additional costs. The total amount of HEA oil used in film forming is not more than a few hundred tons/year. This area is not expected to expand much in the near future (Fulmer, 1985; Pryde and Carlson, 1985).

Surface Agent. The fatty acids contained in HEA oil are used widely as cationically active surface agents in a variety of applications, ranging from fabric softeners with bactericidal activity to dispersants and corrosion inhibitors in petroleum products (Shapiro, 1968). For instance, the 22-carbon behenyl amine is a component of a preventative of salt water corrosion used by the U.S. Navy. It was the only amine of those tested in the formulation that met the Navy's stringent requirements (Nieschlag and Wolff, 1971). Another application of rapeseed oil is the use of brassylic acid as a surface active agent, for which its long hydrocarbon chain is favorable (Appelqvist and Ohlson, 1972).

Glossy Agent. The hydrogenation of crambe oil yields a glyceride, which contains saturated fatty acids. This triglyceride has a glossy surface and about the same melting point as beeswax (63 to 65° C) but is much harder (Pattison, 1968). The production of hard waxes, suitable for the manufacture of shoe and floor polishes, also has been reported by Appelqvist and Ohlson (1972). This was achieved by the esterification of behenic acid with ethylene glycol. Princen and Rothfus (1984) mentioned research showing that liquid wax esters from crambe oil were of better quality than those from rapeseed oil. Other minor uses of HEA include packaging for food. Erucamide is well known for improving stick resistance (Princen and Rothfus, 1984). It's use in food packaging is permitted by the U. S. Food and Drug Administration.

High Temperature Lubricants

A traditional use of rapeseed oil was lubrication, but changes in industrial techniques and availability of less costly, synthetic derivatives have eliminated the need for this oil. For instance, rapeseed oil was used to lubricate steam locomotives. The use of rapeseed oil now is limited to a mixture for which its characteristics are expressly needed, again because of its high cost.

Exclusive use of fatty oils is unusual today, but combinations of fatty and mineral oils are used commonly. Actually, the fatty oil orients itself on metal surfaces, and the mineral oil is "sandwiched" between the layers. The coefficient of friction is generally lower for the fatty oils. The problem with vegetable oils is that they get gummy and carbonize as the temperature increases. This problem is overcome by blending with mineral oils in calculated proportions (Appelqvist and Ohlson, 1972).

Rapeseed oil is used for many different purposes under high temperatures. Quenching of metal is the process of withdrawing heat from metal rapidly to obtain a required structure. Rapeseed oil serves as an additive in quenching oil, because it increases the cooling rate. One other major utilization of rapeseed oil is in the steel casting industry. Core oils are used as binding agents for sand cores in hollow metal casting. They are prepared by mixing approximately 50 parts by volume of sand with 1 part of oil, molding the mixture in a wooden form, and baking at a temperature of 200 to 230° C until a hard, coherent mass is formed. At this temperature, only HEA oil remains on the mold long enough to provide efficient lubrication (Nieschlag and Wolff, 1971).

In cooperation with a major steel producer, crambe oil was tested as a mold lubricant and found to be superior to rapeseed or any other oil then being used. Another steel producer found in tests with crambe that less oil was required than with rapeseed oil to give results of comparable quality. In both trials, crambe oil produced less smoke and wet the mold surface better (Nieschlag and Wolff, 1971).

Assuming that most modernized facilities employ continuous casting, the market for suitable lubricants could be substantial. However, substitutes for oil also can be employed, like an inorganic powder. During casting, this powder melts and forms a protective film over the molten steel. The film lubricates the mold and also prevents oxidation of the steel. However, some processors still have difficulties in handling this material and prefer using rapeseed oil.

Rapeseed oil also is employed as a sulphurized lubricant. Kammann and Phillips (1985) reported that rapeseed oil had the most favorable content of monounsaturated and long-chain fatty acids for this purpose.

Low Temperature Lubricants

As an additive, HEA oil tends to increase the oiliness of mineral oil and to improve its durability under high speed and high pressure operating conditions. Mineral oil mixtures that contain HEA oil also form stable emulsions with salt water and have been used as marine lubricants. They also are used as spinning lubricants in the textile industry and as rolling oils in the processing of light gauge steel, where oils with a low coefficient of friction are desired. Rapeseed is still a significant part of the formulations of lubricants used by the British railroad (Nieschlag and Wolff, 1971).

Use as a dielectric fluid (a nonconductor of direct electrical current) also has been mentioned (M.G. Blase, personal communication, 1988). The only barrier seems to be the cost of rapeseed oil. Researchers are trying to develop this application and to investigate the potential market.

Miscellaneous

Brassylic acid is used as a fixative in the perfume industry in the form of ethylene brassylate. Large-ring compounds containing 15 to 17 carbon atoms often are substituted for natural musk to enhance the odor of fragrant components in perfume formulations (Appelqvist and Ohlson, 1972).

Erucic acid can be combined with sodium to form a salt for use in hot water detergents (Ohlson, 1983; Princen and Rothfus, 1984). Sulphated rapeseed oil alcohols have shown very good foam and detergent properties and also are used in the preparation of washing compounds.

Uses in the pesticide industry also have been reported by many authors, although no thorough study has been done so far. However, important potentials exist for employing vegetable oils in the application of pesticides to crops (Kapusta, 1985). Appelqvist and Ohlson (1972) reported the utilization of rapeseed oil to stabilize fungicide and insecticide suspensions in paraffin oils. Another fairly new use for rapeseed oil is as a spray for weed control instead of common petroleum sprays. One major advantage of vegetable oils as postemergence weed sprays is that they offer little hazard of crop injury or harmful residues.

Chemicals based on rapeseed oil are employed for three general purposes in the textile industry: scouring, washing, and dyeing (Appelqvist and Ohlson, 1972). Rapeseed oil, and more specifically rapeseed fatty amine condensate, mixed with various glycols and water is used to remove the grease and oil from wool. Another solution containing the amine condensate is used to wash fabric before and after printing. The same amine also is used to reduce and most often completely eliminate the formation of surface scum during the dyeing operation.

Rapeseed oil also has been used in specialized inks. Incorporated as 13 percent blown oil, it acts as a drying agent in the ink and forms a film on the surface, thereby preventing excessive penetration of the ink. It also is recommended in the process of printing with a glossy finish on leather. The blown ink is employed particularly as a wetting agent and as a vehicle for emulsion inks (Appelqvist and Ohlson, 1972).

The mining industry offers another potential market. Tests are being done to determine if HEA oil can be used as a flotation agent to separate minerals from aggregate (USDA, 1989).

The tanning industry is known to use rapeseed oil for special purposes (Appelqvist and Ohlson, 1972).

Summary

Its long-chain fatty acid composition makes HEA oil unique and valuable for industry. Erucic acid; its derivative, erucamide; and its cleavage products, brassylic acid and pelargonic acid, all have industrial uses. It is technically feasible to synthesize a similar oil in a laboratory, but the costs involved would be prohibitive. One established market for HEA oil exists, i.e., use as a slip agent for plastics. Other potential markets are being studied, and some require further research on processing and uses. Initial contacts with industry representatives have been made by members of the HEA Oil Project (USDA, 1989). Commercialization and marketing of the oil in the United States are being pursued.

PRODUCTION AND MARKETING AREAS

The current HEA oil market in the United States is about 6,000 to 8,000 tons/year. This small amount of oil is imported annually from Europe and Canada (Kramer et al., 1983). The policies of these two areas will be examined in order to estimate their competitive capacity.

Europe

Europe is a major rapeseed-producing area in the world. Rapeseed production increased three- to fourfold after World War II, for two reasons. First, Europe tried to overcome the shortage in edible oil. Second, Europe tried to decrease its dependence on the United States for soybean meal. This trend has accelerated, particularly since the embargo in 1970.

These developments have been beneficial in terms of a better balanced agriculture, particularly in northern Europe. Most production is of winter rape varieties, which give high yields. In recent years, production has increased most in France, West Germany, the United Kingdom, and Denmark (Table 21). For instance, French production doubled between 1986 and 1987. This increase was due partly to a very favorable market condition (subsidies are paid to both the producers and processors of EEC-grown rapeseed). The lower cost of domestically produced rapeseed encouraged crushers to use it preferentially.

Eastern European countries (Poland, East Germany, Czechoslovakia, and Hungary) are major producers of rapeseed and oil, but export relatively little (less than 10 percent) (Table 22). On the other hand, Sweden and Denmark also produce large amounts of rapeseed and export half of the seed and 60 percent of the oil. A third group of countries (France, West Germany, United Kingdom, Netherlands, Italy, and Finland) characteristically has both high production and high consumption of rapeseed oil. In the published agricultural statistics, it is not possible to distinguish between HEA and LEA varieties. However, HEA varieties are becoming less important and account for only a small percentage of total exports.

Table 21. Development of rapeseed production in Europe from 1977 to 1987

Country	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
					–thousands of tons–						
Belgium-Luxembourg	1	3	1	2	2	6	11	12	10	10	10
Denmark	80	115	150	200	280	350	340	577	575	613	670
France	388	500	510	1,100	978	1,134	908	1,300	1,318	1,040	2,664
Ireland	–	–	–	1	1	5	7	15	14	6	10
Italy	3	3	1	2	1	1	1	10	15	50	50
Netherlands	31	27	18	29	36	33	37	37	30	20	35
United Kingdom	143	165	198	300	340	570	580	923	890	971	1,250
West Germany	268	300	322	378	363	535	600	662	805	956	460
Total	914	1,113	1,200	2,012	2,001	2,634	2,484	3,536	3,657	3,666	5,149

Data from Anonymous, 1988b

Table 22. Annual production and trade of rapeseed and rapeseed oil in various European countries, 1977-81

	Rapeseed			Rapeseed Oil		
Country	Production	Import + Export -	Net	Production	Import + Export -	Net
			–thousands of tons–			
Czechoslovakia	150	+10	160	60	+ 2	62
Denmark	120	-110	10	5	-3	2
Finland	50	–	50	20	-3	17
France	620	-90	530	220	-160	60
Germany, E.	290	-20	270	110	-7	103
Germany, W.	310	+400	710	240	-110	130
Hungary	80	-10	70	30	-4	26
Italy	2	+70	72	30	+40	70
Netherlands	30	+80	110	40	-10	30
Poland	640	-40	600	210	-20	190
Sweden	270	-90	180	70	-40	30
United Kingdom	180	+140	320	130	-10	120

Data from Kramer et al., 1983, calculated from USDA data, 1981

Table 23. Oilseed crushing and refining capacity by state

State	Crushing Capacity	Refining Capacity
	–tons/day–	
Alabama	3,800	0
Arkansas	6,200	0
California	235	130
Delaware	1,100	325
Georgia	4,400	350
Illinois	25,950	1,325
Indiana	7,300	950
Iowa	14,900	1,540
Kansas	3,600	350
Kentucky	1,000	0
Louisiana	1,400	0
Maryland	900	325
Minnesota	7,900	680
Mississippi	3,100	0
Missouri	5,900	360
Nebraska	2,400	900
North Carolina	4,090	440
Ohio	3,400	190
South Carolina	2,900	200
Tennessee	3,900	325
Virginia	1,500	0

Data from American Soybean Association (personal communication, 1988)

In the past, the European common market countries have imported and crushed oilseed, mainly soybean, in order to produce large quantities of high protein meals for animal production. In recent years, these countries have become partly self-sufficient in oil and meal, largely because of their production of “00 varieties” of rapeseed, low in both glucosinolates and erucic acid.

Thus, the trend is to grow exclusively “00 varieties” in order to produce sufficient quantities of edible oil. For this reason, European countries probably will not become commercial competitors for HEA oil, even though their technical skills and recent experience could make them competitive. If the HEA market increases in size, a very compatible trading arrangement could be developed between Europe, specializing in edible oil, and the United States, specializing in HEA oils for industrial purposes.

Canada

Canada is the world’s leader in terms of production and export of rapeseed, amounting to 3,463,000 tons in 1985 (Röbbelen et al., 1989). This position has been achieved largely within the last decade. Spring rape varieties are grown there; no winter varieties suited to the Canadian climate are commercially available.

Canada also has led the world in the development and production of LEA, low glucosinolate varieties of rapeseed (canola). Almost 100 percent of the recent Canadian production was of these varieties (Thomas, 1984).

According to Kramer et al. (1983), 200,000 to 300,000 acres in Canada are devoted currently to the production of HEA oil for industrial use. Research is being done to develop HEA, low glucosinolate varieties adapted to local conditions. However, there is no known research on industrial utilization of the HEA oil.

Current Canadian policy emphasizes production and development of canola. This leads to the conclusion that Canada shouldn’t be a strong competitor in the production of HEA oil. Canadians are much more interested in continued commercialization of canola, to ensure their position as a supplier of the major share of the world market. Canada already is the major exporter of canola oil to the United States.

A three-sided world market for HEA oil could develop easily. The technical potential exists for both Canada and Europe to become involved in the HEA market. Presently, the marginal production of HEA rapeseed is considered a burden in these areas, because it is not part of their overall policy program. However, this situation could change. A growing HEA market might be attractive for those who are more experienced in producing and crushing the seed. United States authorities need to develop a leadership position in this market before other countries. This would have to be achieved with a subsidy policy for production, as well as funds for research and development of the industrial utilization of the oil.

Potential in the United States

Production

Rapeseed and crambe seem to be well adapted to various soils and climates. However, several trials have been conducted to estimate differences among states for rapeseed cultivation (see Tables 2-6). Some of the results are summarized below.

1. Seed yields observed in the different trial locations have varied widely. Yields were highest in the Northwest and intermediate in the Midwest and Southeast. However, these yields were not statistically tested, and further experiments should be conducted.

2. Oil content in the seed was homogeneous in the different trials, averaging around 40 percent.

3. The erucic acid content in the oil was not influenced by location. The differences observed were not significant.

4. The glucosinolate content in meal after extraction of the oil showed no significant differences between locations.

No comparative cost studies have been made in various locations. However, there are no specific costs for rapeseed production that should be susceptible to significant differences among various areas of the United States.

Therefore, no major characteristics of producing rapeseed provide advantages or disadvantages for one state over others. However, certain considerations in favor of Kansas should be mentioned. Kansas has been a major crop producer for decades. Its transportation network is well developed and well adapted to shipping crops. Kansas also is located centrally among both production areas and potential demand areas. These facts should contribute toward lower costs for transportation of seed and oil.

Crushing

Two major elements influence competition at the crushing stage. First, it was demonstrated that the return on investment and costs involved are better controlled when crushing and refining are combined in the same plant. Second, HEA oilseed should be crushed in existing facilities, at least until the HEA oil market has sufficient volume to keep separate plants operating. This can be achieved readily without a major, additional investment.

To determine the kind of processing plant to develop, four classes of potential and current uses of HEA oil should be considered: 1. plastics, nylon, or rubber; 2. high temperature lubricants; 3. low temperature lubricants; and 4. coatings.

An examination of the literature shows that there is no plant in the United States crushing exclusively HEA oilseed. Crushing is done either in Canada and Europe or on a sporadic basis in this country.

The financial recession of the early 1980s, associated with increasing world competition and lower prices, led to a substantial restructuring of the vegetable oil industry in the United States (Amer. Soybean Assoc., personal communication, 1988). Five processors now control over 80 percent of the total crushing market for soybeans. Most of the California plants have been closed down, and several have been (or will soon be) closed in Texas and Oklahoma. This restructuring probably also will affect the refining sector.

Plants are scattered throughout the country, with crushing and refining capacities largely concentrated in the Midwest and South (Table 23). Many of these plants are being confronted with problems of pollution control.

In Kansas, one of the three oilseed plants combines crushing and refining operations. Its crushing capacity is 1,000 tons/day, and its refining capacity is 350 tons/day. This facility is an asset for Kansas, because Texas, Oklahoma, Arkansas, Louisiana, and some southeastern states do not have combined crushing-refining units. Most of them are located in the midwestern soybean-growing area.

Kansas has a competitive advantage over western and northeastern states, which do not have crushing facilities. Also, most of these states are not major crop producers, which might favor Kansas as a location for any new crushing-refining plants.

Only a few states have shown an interest in developing oilseeds and a market for them: Kansas, North Dakota, Iowa, Nebraska, New Mexico, Idaho, and Missouri. Among these, four can be considered as having a definite advantage: Iowa, Nebraska, Missouri, and Kansas. These have a sound crushing-refining industry, are centrally located, and have ready markets for meal as livestock feed.

Summary

Europe and Canada are major producers of rapeseed, but specialize in varieties with edible oil. However, both areas have potential to become involved in the HEA oil market. Thus, the United States should take a leadership role in the marketing of HEA oil before other countries do. Crambe and rapeseed can be grown successfully in several parts of the country. However, Kansas and a few other central states have an advantage in location and existing facilities for crushing and refining.

FACTORS AFFECTING MARKETS

Several external factors might have influences on the HEA oil market. Impacts on a "potential" market are difficult to quantify, but some possible effects of these factors will be pointed out.

Legislation

Legislative changes could have a significant impact on development of a market for HEA oil. Legislators set the legal limit for glucosinolates in meal. The last amendment was published in June, 1981 and included only crambe meal, limiting the amount to 4.2 percent in cattle rations. If the toxicity of crambe meal is removed, this restriction could be changed, and commercialization of the meal could begin. Marketing small amounts of crambe and rapeseed meals does not create any problems. However, expansion of the HEA market could lead to problems requiring legislation. First, the current limits on the use of meals in rations restrict sales. Second, in the long run, these meals would compete with soybean meal.

New Products

The market or demand for HEA oil will depend on whether or not useful, new products can be developed. This requires accelerated research programs. For instance, nylon 13-13 and certain new plastics made from HEA oil have properties that make them useful in automobile engines. Some demonstration research could lead car manufacturers to use nylon or plastic for some engine components. According to M.G. Blase (personal communication, 1988), this possibility is being studied currently by the automobile industry. Plastic is less costly to maintain than metals. Then, HEA oil would be the source of these needed materials, and the market for rapeseed and crambe would be enhanced.

Rapeseed and crambe oils can be substituted for many petroleum products. Most often, research to find such substitutes has been funded during times of shortage (e.g., World War II) or during an energy crisis. However, petroleum supplies can be unreliable, irregular, or completely depleted in some areas. Thus, renewed research on petroleum substitutes would be appropriate. No doubt a safe and regular market for HEA oil could have an overall, competitive advantage, as long as a favorable price relationship between the two raw materials could be maintained.

Members of the USDA High Erucic Acid Oil Project are developing market contacts for uses of erucic acid or its derivatives as dielectric fluids, flotation agents, paint additives, and lubricants (Van Dyne et al., 1990).

New Technology

New technology might influence the equilibrium of the market in three areas: production, crushing, and utilization.

Major improvements expected at the production stage rely on genetic progress. The best solution to the glucosinolate problem appears to be genetics. Development of a low glucosinolate-HEA variety, adapted to any climate and resistant to diseases, would considerably affect the costs of production and, therefore, the entire market. Varieties with increased yields also would reduce production costs. The variable yields noted above for rapeseed and crambe indicate genetic capabilities of the plants to yield more seed.

New technology at the crushing stage should lead to development of new equipment and techniques better adapted to the specific processing of rapeseed and crambe. Large quantities of crambe seed are being grown for a test crushing to evaluate methods and equipment (Van Dyne et al., 1990). This might allow more efficient and less costly processing. The major problem currently is meal detoxification. The water-washed system is very good, but it has not been used in a commercial-scale plant and neither have other available methods.

Switching from regular oilseed crushing to HEA oilseed crushing requires stopping the plant, while equipment is cleaned. New equipment, better designed and suited to rapeseed and crambe seeds, should simplify the operation, shorten the changeover time, and lower the costs involved.

Obviously, the utilization stage is crucial. New technology developed in industry leads to new products and new uses. For example, there is a potential market for nylon 13-13, but current processing costs are not competitive. New technology that lowers cost could generate interest in using this product.

Summary

Factors that can affect the HEA oil market include legislation, new products, and new technology. Legislation limiting use of crambe and rapeseed meals in animal feeds is a problem. Development and marketing of nylon, plastics, and other petroleum substitutes involve technical and economic considerations. Technology can improve seed production and processing of HEA oils to make them more competitive.

CONCLUSIONS

The alternative, value-added crops, rapeseed and crambe, can be grown successfully in Kansas. Basic agronomic practices have been established. Location does not significantly influence content of either erucic acid or glucosinolate. The variety Bridger has been highest in yield and erucic acid content, while having a low level of glucosinolate.

Expected yields for rapeseed and crambe in the United States are comparable to those found in other producing countries. An estimated, profitable price of

10.6 cents per pound would require yields to average 1,286 pounds per acre. Such yields already have been attained in Kansas and northwestern states.

With a few exceptions, crushing techniques for HEA oilseed are similar to those used for other oilseeds. Therefore, HEA oilseed could be crushed in existing facilities that now handle soybean or sunflower seeds. The most economical method would be to crush HEA oilseed once a year, during the slack season for other seeds. Rapeseed and crambe are less expensive to process than soybeans because of their higher oil content. Total costs of rapeseed oil can be as low as 30 cents per gallon.

The major by-products of oil production, crambe and rapeseed meals, can be used in animal feeds. Improved varieties with less glucosinolate and/or better methods of removing glucosinolates from meal are needed. Until these are available, the amount of crambe or rapeseed meal in feeds must be restricted. Kansas would be an ideal market for meal, because of its cattle feeding industry.

The composition of HEA oil gives it unique and valuable properties for industrial uses. Some markets already exist and others are being developed in the United States. HEA oil can serve as a substitute for petroleum products in plastics, nylon, lubricants, and other materials.

Europe and Canada are major producers of rapeseed, but specialize in varieties yielding edible oil (canola). Therefore, the United States could develop the HEA oil varieties in several areas. Kansas and a few other central states have an advantage in location and existing facilities for crushing and refining. Producing HEA oil in the United States would reduce use of depletable resources (like petroleum), reduce imports, and strengthen domestic business and industry.

Results of this study indicate that the current United States market for HEA oil is not great enough to warrant large-scale production of rapeseed and crambe as alternative crops. However, the market can be expanded by legislation, new products, and new technology. Some industrial sources estimate a demand for HEA oil that would require about 30,000 crop acres by 1992 and 100,000 by the year 2000.

Institutions involved in the USDA's High Erucic Acid Oil Project continue their efforts to establish rapeseed and crambe as commercial crops, by developing markets for primary products and by-products. To take advantage of these new markets, domestic production of crambe and rapeseed must increase. Thus, the HEA Oil Project emphasizes simultaneous development of production and markets. As a participant in this project, Kansas will benefit from its achievements.

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