BREEDING FOR QUALITY

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In recent years breeding for rapeseed quality traits has been given a priority at least equal to that of seed yield. This departure from the norm results from a combination of market pressures for an improved rapeseed quality package and the development of rapid, accurate analytical techniques to detect many of the important quality components. Prior to 1970, rapeseed breeders were concerned primarily with seed and oil yield, disease resistance, and, in some cases, winterhardiness. Today the list of selection criteria must also include erucic, linolenic and linoleic fatty acid levels in the oil, and the glucosinolate, protein and fibre content of the meal, while the presence of sinapine and polyphenols cannot be overlooked. Many of these quality components are yielding to selection pressure as will be evident in the technical papers presented to this session. However, it must be realized by the industry that every additional quality component demanded by the consumer multiplies manyfold the resources which the breeder must employ if seed and oil yield are to be maintained or increased. Thus the development of a new look in rapeseed and its products may involve some slowing of the rate of advance as well as some risks and sacrifices by both the producer and the primary processor. However, the data to date suggest that over the longer term there are large returns to be obtained from breeding for quality.

The introduction of the first low erucic acid varieties, such as Oro, Span, Sinus, and Lesira resulted in a reduction of seed and oil yield potential. Fortunately, breeders quickly produced replacements such as Midas, Torch, Primor, Brink and Quinta that were equal or superior agronomically to the old high erucic varieties. The availability of quality oil from these and other new varieties not only protected the rapeseed oil market but also, in Canada at least, changed the pattern of oil usage. In the Canadian market low erucic acid oils have proven to be particularly well suited as a liquid oil and for the manufacture of partially hydrogenated, winterized salad oils (Teasdale, 1965). This is because low erucic oil is different physically from soy, palm, or high erucic rape oil in that nearly all (≈93%) of its fatty acids have 18 carbon chains. As a result, low erucic acid rapeseed oil has steadily increased its share of the Canadian salad and cooking oil market from 37% in 1970 to over 53% in 1977 in a market which has grown from 55,000 mt to 103,000 mt over the same period (Table 1). The new physical structure, however, did restrict the amount of low erucic oil that could be used in the manufacture of a margarine because glyceride molecules with a preponderance of one common fatty acid carbon chain length to form crystals in stored margarine. Fortunately, there are now indications that processing technology can overcome this problem and that quality margarines with a very high rapeseed oil content will again enter the market. Thus, the new quality rapeseed oil now has the potential of capturing an even greater proportion of the market than that currently held.

A similar but even more encouraging pattern of events is developing following the breeding and utilization of varieties containing low levels of glucosinolates. It is accepted generally that seed which contains less than 2 mg or 17.9 μmoles/g of the normally measured glucosinolate

Table 1. Proportion of rapeseed oil used in the production of refined, deodorized salad oils in Canada 1969 to 1977 *

Year	Total salad oil prod. '000 mt	Rape oil % of total
1969	55	37
1970	55	37
1971	57	41
1972	66	47
1973	69	48
1974	76	43
1975	80	48
1976	94	50
1977	103	53

* Data source: Statistics Canada, Oils and Fats.

breakdown products in the moisture-free, oil-free meal can be classified as low glusinolate rapeseed. Varieties termed "double low" are those whose seed is both low in glucosinolate and erucic acid content. The first double low varieties produced in Canada and Europe, such as Tower and Erglu, were lower yielding than the improved low erucic varieties they were to replace. Nevertheless, Canadian producers have responded to the increased market opportunities for double low varieties ever since commercial production was initiated in 1974. Almost 43,000 ha or one-third of the 1977 Canadian crop was sown to double low varieties, and 800,000 ha are expected to be sown to double low varieties in 1978. The appearance of new low glucosinolate varieties such as Regent and Altex, with equal or superior seed yield to the best low erucic varieties, will further speed the Canadian conversion.

Commercial acceptance of low glucosinolate meal has been excellent. Nutritionists, utilizing commercially processed low glucosinolate meals, conservatively recommend that the safe limits for such meals can be increased 33 to 100% for the various classes of poultry, while usage in swine rations could be increased safely two- to three-fold (Clandinin and Robblee, 1976). In response to the continued Canadian and export market pressure for low glucosinolate seed, the first double low spring turnip rape (B.campestris) variety, Candle, was introduced into commercial production in 1977. This introduction has been successful despite Candle's potentially lower seed yield. European breeders are also working toward double low varieties of winter rape, but it is not a simple task or one which can be done overnight. It has been suggested that the market response to double low varieties in Europe may not equal that experienced in Canada since most of the present rapeseed meal now finds its way into dairy and beef rations where the presence of glucosinolates is less of a concern. Be that as it may, there can now be little doubt that agronomically superior double low varieties can be developed in summer and winter forms of both rapeseed species. It is also clear that their commercial utilization will bring about an improved competitive position and expanded market opportunities.

As significant as these developments may be, they are but the first major steps along the road to the ultimate rapeseed quality package.

Although most of the glucosinolates have been bred out of the double low varieties, breeders and processors must realize that we have not been as successful as was originally thought. Initially it was reported that the new double low varieties, such as Tower and Erglu, contained approximately one-tenth the level of glucosinolates which were present in standard high glucosinolate varieties (Stefansson and Kondra, 1975; and Röbbelen, 1976). Unfortunately, it appears that breeders and nutritionists have not been measuring all the glucosinolates present. Beside the small amount of glucosinolate breakdown products (8 to 18 µmoles/g), normally measured in double low rapeseed meal, it now appears there is an additional 5 to 13 µmoles that have previously gone undetected. These additional glucosinolates are thought to be indolylglucosinolates (McGregor, 1978). Because such compounds would originate along a different biosynthetic pathway and yield thiocyanate ions rather than isothiocyanates or oxazolidinethiones breakdown products, they have not been detected by the standard glucosinolate test methods and their level in low glucosinolate meal is essentially unchanged from that found in high glucosinolate seed. Some variation in the content of these additional glucosinolates exist within and between Brassica species, but to date no selections have been reported with less than 5 µmoles/g of meal (McGregor, 1978). The presence of this additional small amount of glucosinolate to the known total should not detract from the importance of double low varieties. However, it does present an additional hurdle to the development of varieties with extremely low glucosinolate levels. In order to speed this development there is an urgent need for a single, fast and accurate method for determining the presence and amount of each and every glucosinolate present.

The reduction of glucosinolate levels immediately focuses attention on protein and fibre content. These quality components are likely to be the limiting factors in future rapeseed meal utilization. Protein content is a significant factor in determining meal value as a livestock feed and as a fertilizer. However, several authors have reported negative correlations between the percentage of oil and protein (Appelqvist, 1972). Although these results suggest it would be difficult to increase oil and protein at the same time. Stefansson has demonstrated that with the proper breeding procedures significant advances can be made in both quality traits (Grami and Stefansson, 1977; Stefansson and Kondra, 1975). Selection for the sum of the percentage of oil plus the percentage of protein in the seed of segregating populations has resulted in a simultaneous increase in the level of these two most valuable rapeseed components in spring rape (Table 2). This breeding technique has given new direction to many breeding programs which should result in a greater value being built into the seed future varieties. Indeed the high protein content of Tower rapeseed meal has been of considerable economic importance and has assisted greatly the successful introduction of low glucosinolate meal into the Canadian market.

Table 2. Effect of selection for oil content versus sum of oil plus protein as a percent of seed in Canadian varieties of spring rape

Variety	Selection technique	Erucic + glucosin.	% of seed Oil	% of seed protein	Sum oil + protein
Midas	Oil	Low E	42.6	28.1	70.7
Tower	Oil + prot.	Low E & G	42.1	31.3	73.4
Regent	Oil + prot.	Low E & G	42.9	30.6	73.5

The incorporation of the yellow seed coat characteristic into adapted double low varieties will augment the selection process advocated by Stefansson. Yellow seeds of rape and turnip rape contain a higher proportion of both oil and protein and have a lower percentage of fibre (Stringam et al., 1974; Jonsson and Bengtsson, 1974). These improved quality traits are primarily due to the characteristically thin hull in yellow seeds, but the heavier, higher oil content embryos found in such seed also contribute to the desirability of the yellow seed package. Yellow seed is also pleasing in appearance and will permit feed formulators greater freedom to alter their formulas without visually changing the product. The oil from yellow seed is generally lighter in color and the presence of chlorophyll in the seed can readily be seen. This latter feature may reduce the tendency for producers to harvest too early (Jonsson, 1975).

The improved quality characteristics of yellow-seeded turnip rape strains and varieties are indicative of the potential in both species for a new plateau in oil, protein and fibre content. The commercial introduction of the partially yellow-seeded, double low variety Candle has already altered Canadian processors and feed formulators to the immediate advantages of yellow seed. However, a much greater advance is still possible as illustrated by the oil, protein and fibre content of the large, pure yellow-seeded R500 variety of Yellow Sarson (Table 3).

Table 3. The relationship of oil, protein and fibre content and the seed color of three Canadian turnip rape varieties grown in Saskatchewan, 1976 and 1977

Variety	Erucic and glucosinolate	Seed color	Percentage of oil[1]	protein[2]	fibre[3]
Torch	Low E, Hi G	Dark Brown	39.9	41.6	14.2
Candle	Low E & G	Part Yellow	42.2	42.2	10.9
R500	Hi E & G	Pure Yellow	44.5	47.0	8.2

[1]Moisture-free basis; [2]oil and moisture-free basis; [3]crude fibre in oil and moisture-free meal.

Although a reduction in fibre level is of little consequence in cattle feed formulations, it is of prime importance for expanding meal use in poultry and swine rations. There are indications, however, that pigment-free, low-fibre rapeseed meal offers poultry and swine feeders more than just increased available energy. Low fibre oilseed meals are reported to have a much improved protein digestibility (Lodhi et al., 1976), while the lower levels of polyphenols in hulls from yellow seeds (Theander et al., 1977) may lead to an enhanced protein availability. Unfortunately, selection for yellow-seeded B. napus has yet to yield agronomically acceptable strains with a genetically stable yellow colored seed. As a result, many breeders are now resorting to interspecific crosses to introduce the oleracea genome containing the yellow seed coat gene(s) into a resynthesized B. napus. Since pure yellow-seeded plants are known to exist in B. oleracea and B. carinata, both species are being used as putative parents in crosses with lines of yellow-seeded B. campestris.

Other minor components in the seed may also affect meal quality for a specific type of animal. For example, a fishy odor problem in eggs may occur if rapeseed meal is fed to brown-shelled egg layers (Hobson-Frohock et al., 1975). Recent evidence indicates that sinapine, present in significant quantities in rapeseed cotyledons, may be the precursor to the offending trimethylamine (Hobson-Frohock et al., 1977). Although a range of sinapine levels has been found in the rapeseed species and their close relatives, no seed has yet been reported with very low sinapine values. The proof that the problem originates with a given level of sinapine undoubtedly will stimulate breeding efforts to reduce its level, but rapeseed breeders would prefer to see the poultry geneticist correct the deficiency within the brown-shelled egg layers. Unfortunately, the inheritance of this trait in poultry is complicated and no simple test has yet been devised to identify the presence of the offending gene in either sex (Bolton et al, 1976).

The quality of rapeseed oil may also be improved through further changes in its fatty acid composition. Economically and perhaps nutritionally the most important changes would be to increase the proportion of linoleic acid, and essential component of animal diets, while at the same time reducing the level of the easily oxidized fatty acid, linolenic. Changing the content of these polyunsaturated fatty acids is technically and genetically more difficult than the modification which has been accomplished with erucic acid. The selection for various levels of erucic acid was simplified because there were no more than two major additive genes involved; the zero level provided a finite base to work from and the erucic content would be measured relatively quickly. In selection for improved levels of the two polyunsaturated fatty acids, several genes are thought to be involved and there are both maternal and embryonic influences to be considered (Kondra and Thomas, 1975; Thomas and Kondra, 1973), while each analysis is more time-consuming. The breeding problem is also confounded by the relatively narrow range in variation for the polyunsaturated fatty acids and the sensitivity of these fatty acids to environmental conditions during oil deposition and seed maturation (Jonsson, 1975a). Further, the levels of these two fatty acids appear to be correlated positively, and probably are products of the same biosynthetic pathway, e.g., oleic $\rightarrow$ linoleic $\rightarrow$ linolenic. Fortunately, correlations can be broken. Strains of spring and turnip rape have now been selected from low erucic varieties which yield over 30% linoleic acid without significantly increasing the level of linolenic acid (Kondra and Stefansson, 1970; Jonsson, 1975b). There are, however, differences in opinion between countries and scondary processors as to whether top priority should be to raising the linoleic content or reducing the level of linolenic. Studies by Röbbelen and coworkers with spring rape suggest that the most rapid advance toward the dual goal is likely to come from separate selection for each fatty acid within progeny from mutagen-treated seed (Röbbelen and Nitsch, 1975). The desired combination of high linoleic, low linolenic can then be selected from progenies of intercrosses between the high linoleic and low linolenic breeding lines. In addition, they have found such intercrossing increases the fertility and vigor of the progeny over that of either parental line. The results reported from their program indicate that under West German growing conditions it should be feasible to combine a level of over 30% linoleic with a 3.5% level of linolenic in an agronomically acceptable cultivar. Thus despite the difficulty of this breeding problem and the large investment required in manpower and equipment, significant progress is being made towards an even more desirable rapeseed fatty acid composition.

The object of all these quality breeding programs is to make a good product even better. There can be little doubt that the opportunities to improve rapeseed quality through plant breeding are as bright today as they were 20 years ago when modern analytical techniques were in their infancy. Recently, Stefansson (1978) suggested a hypothetical set of specifications for No. 1 Canada rapeseed which could be a reality by 1980 (Table 4).

Table 4. Hypothetical specification for No. 1 Canada rapeseed in the 1980's

Seed color		yellow
Erucic acid	less than	0.1 %
Linolenic acid	less than	4.5 %
Linoleic acid	more than	30.0 %
Glucosinolates	less than	7 μmoles
Fibre content of meal	less than	10.0 %
Sum of oil + protein in the seed	more than	73.0 %

Given the time frame, the task of combining all these quality characteristics in the spring forms of rapeseed is formidable. Further, the development of such varieties in the winter forms will undoubtedly take considerably longer since most of the important quality characteristics must be transferred from spring into winterhardy material. However, such a quality package brings with it substantial economic advantages. Thus, it is more important than ever before that a spirit of cooperation and timely exchange of basic genetic material and information be fostered. Only in such a climate can maximum quality gains be achieved in the shortest possible time.

REFERENCES

Appelqvist, L.-Å., 1972. In Rapeseed; cultivation, composition, processing and utilization. L.-Å. Appelqvist and R. Ohlson, eds. Amsterdam, Elsevier, 391 p.

Bolton, W., T.C. Carter and R.M. Jones, 1976. Br. Poult. Sci. 17:313-320.

Clandinin, D.R. and R.A. Robblee, 1976. In Proc. Annu. Meet. Rapeseed Assoc. Can. 9, Winnipeg, pp. 41-46.

Grami, B. and B.R. Stefansson, 1977. Can. J. Plant Sci. 57:625-631.

Hobson-Frohock, A., G.R. Fenwick, R.K. Heaney, D.G. Land and R.F. Curtis, 1977. Br. Poult. Sci. 18:539-541.

Hobson-Frohock, A., G.R. Fenwick, D.G. Land, R.F. Curtis and A.L. Gulliver, 1975. Br. Poult. Sci. 16:219-222.

Jönsson, R., 1975 a. Sver. Utsädesfören. Tidskr. 85:9-18.

Jönsson, R., 1975 b. Sver. Utsädesfören. Tidskr. 85:19-29.

Jönsson, R., 1977. Hereditas 87:205-218.

Jönsson, R. and L. Bengtsson, 1970. Sver. Utsädesfören. Tidskr. 80:149-155.

Kondra, Z.P. and B.R. Stefansson, 1970. Can. J. Plant Sci. 50:345-346.

Kondra, Z.P. and P.M. Thomas, 1975. Can. J. Plant Sci. 55:205-210.

Lodhi, G.N., D.S. Sandal and J.S. Ichhpononi, 1976. Z. Tierphysiol. Tierernähr. Futtermittelkd. 37:337-340.

McGregor, D.I., 1978. Can. J. Plant Sci. (in press)

Röbbelen, G., 1976. Fette Seifen Anstrichmittel. 78:10-17.

Röbbelen, G. and A. Nitsch, 1975. Z. Pflanzenzüchtg. 75:93-105.

Stefansson, B.R., 1978. In Proc. Annu. Meet. Rapeseed Assoc. Can. 11, Calgary (in press).

Stefansson, B.R. and Z.P. Kondra, 1975. Can. J. Plant Sci. 55:343-344.

Stringam, G.R., D.I. McGregor and S.H. Pawlowski, 1974. In Proc. Int. Rapskongress, 4, Giessen, West Germany, 99-108.

Teasdale, B.F., 1965. Can. Pat. 726140.

Theander, O., P. Åman, G.E. Miksche and S. Yasuda, 1977. J. Agric. Food Chem. 25:270-273.

Thomas, P.M. and Z.P. Kondra, 1973. Can. J. Plant Sci. 53:221-225.