The Evolution of Rapeseed Quality

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1. Introduction

Two years ago, the 9th International Rapeseed Congress in Cambridge has demonstrated in an utmost comprehensive and impressive manner also the targets, pathways and successes of research and breeding for quality improvement, which happened in rapeseed during the last four decades worldwide. These discussions will be continued in Canberra in two years from now, so that they need not be repeated today at our present meeting.

The Rapeseed Congress events have been moved by the 'Groupe Consultatif' now for 20 years. Although the immediate objective has been of scientific nature, the activities of the GCIRC undeniably have to do with a crop plant, and this means with economic affairs. Every progress of such a crop is most essentially dependent and influential on the existing economic framework, which determines production and final product disappearance. GCIRC from its beginning has tried hard to elucidate potential economic chances and to outline strategies for the early application of scientific results for the production and utilization of rapeseed at commercial scales. The Technical Meetings of the core group of the GCIRC in between two Congresses are particularly suited for such strategical discussions. It may be appropriate 30 years after the first start of rapeseed development towards the 'zero erucic' quality to call to mind, what the issue of this rapeseed quality campaign has been, how it succeeded so far and where we want it to go in the next future. In the following half hour I do not intend, however, to survey for you the situation of rapeseed quality developments in the various countries around the globe nor will I deal with the various botanical species also yielding "rapeseed", like *Brassica juncea*, *B. carinata* or others. I will rather try to shortly outline some principles, which ruled over the developments in Germany from 1965 until now, and to distil from such experience some conclusions, which may have broader relevance to the future of the rapeseed industry.

2. Steps in quality improvement

2.1. Improvement of the rapeseed oil

2.1.1. Zero erucic acid

In the Federal Republic of Germany from a low of 60,000 hectares in the mid sixties, rapeseed is produced today on about 800,000 ha (**Fig. 1**). Seed crushing in recent years amounted to more than 3 mio tonnes, resulting in 1.3 mio t of rapeseed oil and close to 2 mio t of rapeseed meal. Figures on consumption are veiled by imports and exports across German boarders as well as by non-declaration by customers of their oil and meal uses. Presently, much public incentives are given to technical, oleochemical or fuel applications of rapeseed oil. But there is absolutely no doubt, that the utmost majority of rapeseed oil produced in Germany today ends up in the human food sector and this with perfect justification.

Food use of rapeseed oil has a long tradition in Central Europe. But in the late fifties with increasing prosperity in certain countries hesitation was raised against rapeseed oil consumption, which culminated, as some of us will recall, in the International Conference in September 1970 in Ste-Adèle, Canada, and a very few years later in the change-over of rapeseed production to "zero erucic" cultivars. This is the very table (**Table 1**), which the late Bernd Weinberg from the Canadian Department of Industry, Trade and Commerce, Ottawa, showed in Ste-Adèle, representing the new generation of single null (0-)rapeseed cultivars. This zero erucic quality seedoil made rapeseed more than compatible with all other edible vegetable oils in the world market and conditioned the sensational worldwide increase of rapeseed acreage since.

For the plant breeders, such as Keith Downey and Baldur Stefansson in Canada or Jacques Morice in France and others in other countries, this first quality step, although highly demanding in skills and efforts, could be wound up in an unusually short span of time. In some cases these were no more than 6-8 years to the establishment of the first zero erucic cultivars with satisfactory agricultural performance. However, this success was only possible because of a number of prerequitites, which the plant breeder rarely if ever is fortunate to meet in such splendid combination:

- The absolute economic dictation of the (food) market against the traditional commodity, which brought all interested parties into one boat;
- A fixed quality standard (< 2% 22:1), which was soon legalized worldwide, favouring lineal varieties as the adequate category for breeding;
- Genetic source material for breeding freely available thanks to the Canadian colleagues, in particular Dr. Downey;
- Early development of efficient and cheap screening tests as well as accurate methods for the quantitative determination of the quality trait;
- Target character controlled by a few genes only, with major phenotypic effects;
- Target character representing a tissue specific storage compound with no non-replaceable functions (this means with no pleiotropic effects).

2.1.2. Low linolenic acid

This zero erucic trait is and will remain a compulsory quality standard for any food use of rapeseed oil. By removal of the long chain fatty acids, already for mathematical reasons the overall oil composition was changed, too. One consequence was a 20 - 30 % increase of the linolenic acid content in the rapeseed oil, - an undesired change because of the oxidation sensitivity of its three double bonds and the consequent instability and easy off-flavour formation of the derived products. Breeding for "low linolenic", although following a biosynthetic endproduct too, proved much more difficult than "zero erucic" breeding. Yet already in 1973, Gerhard Rakow published data on induced mutants with a blockage of their linoleic acid desaturation. These first mutants and several ones obtained later in Göttingen by origin were obviously monogenic. But their phenotypic expression of the low linolenic character was much more variable by environmental conditions than the zero erucic trait. Above all, this mutant character was not restricted to the synthesis of the seedoil triglycerides, but also apparent in the lipid composition of the cellular membranes, thus interfering with vital cell functions. However, disregarding plant physiologists' predictions, we started a backcrossing programme with the initial mutants (**Fig. 2**) and strongly selected towards the high yield performance of the recurrent parent. This procedure after 6 years and 3 backcrosses, finally raised yields up to normal (Rücker & Röbbelen 1996) indicating that gene function can well be modified by purposive change of the background genotype.

2.1.3. High oleic acid

The first low linolenic cultivar, now being in the official tests in Germany with reductions to below 3 % 18:3 (**Table 2**), showed a concomitant increase in linoleic acid content from the earlier 20 % to about 28 %. This increase had been a particular desire of the margarine industry for nutritional reasons, when the programme was started in the late sixties. Meanwhile human nutritionists are no longer convinced of the beneficial effects of high linoleic acid levels in the diet. But they rather prefer more oleic acid in the oils. In Germany we have also been asked for high oleic acid in rapeseed oil for oleochemical purposes as well as for biodiesel uses in the form of rapeseed methyl ester (RME). Obviously, high oleic acid content meets a rather general demand, so that a programme was launched supported by the Commission of the European Union in Brussels to develop such high oleic acid rapeseed. Traditional breeding methods, including chemical mutagenesis at large scales, finally arrived at several, quite vital mutants (**Fig. 3**) exhibiting oleic acid levels of about 75 %. But other mutants with even higher levels of 18:1showed poor field performance. In repeating earlier analytical approaches we found out that these poor mutants were also high in oleic acid in their root lipids. Apparently, mutative increase of oleic acid in the mitochondrial membranes is more deleterious than an increase of linoleic acid. But after further screening, finally also mutants with high seed specificity and almost normal cellular lipid composition were obtained and these were unimpaired in vitality. In addition, within another cooperative project in Germany, Prof. Heinz from the University in Hamburg successfully elaborates on alternative routes using molecular antisense technology for a directed blockage of desaturase functions. He identified more than 20 desaturase loci in the rapeseed genome and, therefore, it is undoubtedly still some way to go until these efforts will reach their final end of 90 % oleic acid in the seedoil of a productive winterrape genotype.

2.1.4. Increment value of rapeseed oil improvement by breeding

Whatsoever, everything in this world always can be further improved. But for rapeseed oil economically more important is the fact that the zero erucic Canola oil of today is a premium quality product as it stands and that it is highly demanded in the expanding world markets. The attraction of this health food commodity among the vegetable oils, particularly because of its low amount of saturated fatty acids and high share of oleic acid, is also reflected by increasing prices (**Table 3**). Up to 1985, the price difference of rapeseed oil to soybean oil amounted to about 39 US $ / t. In 1996 for the first time in the history, rapeseed oil received higher prices than soybean oil, the usual market leader. This was not caused by chance fluctuation, but is the consequence of a steady trend during the last ten years, resulting an an increment value for rapeseed of more than 400 mio US $ in total.

2.2. Improvement of the rapeseed meal

With the growing rapeseed production the volume of rapeseed meal, the coupled by-product, also increased simultaneously. Presently, an average of 70 % of the profits from rapeseed sales come from the oil and only 30 % from the meal, although feed protein in Europe is in particular demand and rapeseed protein has an extraordinarily high nutritional value well alike soybean protein. Until recently, the utilization of rapeseed meal had been restricted by its glucosinolate content. But since all rapeseed produced in the European Union now is of low glucosinolate quality and contains no more than 18 umol glucosinolates per gram of dry seed, disappearance of the rapeseed meal in the mixed feed has been no problem despite of an increase of total rapeseed production from 1.4 to 3.7 mio t, which is almost threefold (**Table 4**). At times of the first change-over to 00-rapeseed production, the animal nutritionists predicted the potential consumption of rapeseed meal in the European Union to be about 8.5 mio tonnes (Henkel 1985). Presently, farmers in Europe do produce rapeseed according to the EU standards, this is with below 25 umol / g air dry seed (9 % humidity). Certified seeds of cultivars need to be below 18 umol, but further efforts will be required for European winterrape to secure the Canola export quality standard of 12 umol/g. This in particular holds true for the situation of hybrid cultivars. Their breeding will necessitate strict selection measures, since, because of additive gene function, both parental lines must attain the low glucosinolate value, if also the hybrid shall reach the desired low content in its harvest. The German Descriptive List of Released Cultivars (Beschreibende Sortenliste) contains 27 winterrape cultivars for seed production with notified 00-quality. But only two of them exhibit a glucosinolate content of below 12 umol / g (score 2), while another two cultivars range with higher glucosinolate concentrations between 18 and 25 umol / g (score 4). But even with the remaining 23 cultivars producing glucosinolates between 12 and 18 umol / g (according to the official score 3), the low levels of the Canadian Canola exports can not be obtained.

3. Costs of breeding

Altogether, rapeseed development has been most effective during the recent decades. But it must not be overlooked that breeding for additional quality characters has had its twofold charge.

The one constraint concerns the concomitant increase of grain yields. I just remind you of this situation (**Fig. 4**), which has been similarly depicted in different countries to demonstrate that the first cultivars licenced at each step were definitely lower in yield than the preceding cultivars lacking the quality trait. But in their further selections the breeders were most successful in quickly eliminating the drawbacks and with new cultivars they soon even surpassed the former performance. This, however, did not eliminate the time lag in reaching a certain yield level, which was imposed on the cultivars by the need of additional quality selection. Sauermann (1988) elaborated the genetic cost of quality improvement in the form of delayed yield progress caused by such partitioning of the available selection intensity (**Table 5**). The conclusion of his yield selection experiment with due regard *versus* disregard of specific quality characters was, that the resulting cultivars possessing the quality trait were in an average of 6 - 9 % lower in yield than those selected straight-forward for yield only.

In our present situation this fact underlines the immense importance of the incoming hybrid cultivars. With these, the high quality standard of rapeseed reached so far can now be produced in sufficiently high amounts. High yields of a high quality product will strengthen the competitive power of rapeseed in the vegetable oil markets, e.g. as compared to soybean, but also against other crops, such as wheat, which during the recent decades experienced remarkable yield increases. Rapeseed hybrid yields of 5 tonnes or more will stand up more profitable in economic comparisons against the usual 8 or 9 t of wheat.

The second charge of breeding for improved product quality concerns the additional financial costs. The specific analytical determinations of quality together with the necessary performance and disease resistant tests including modern biotechnology are just costly. Herr Brauer has kindly provided this transparency (**Fig. 5**) to demonstrate that the annual expenses spent by the Norddeutsche Pflanzenzucht in Hohenlieth have increased by the factor of 5 from 1979/83 to 1991/95. The biggest portion are labor costs; but consumables are also considerable. Investments have been particularly apparent in 1987-91, when the company heavily invested in biotechnology and molecular genetic methods. These total costs include all breeding efforts, of course; but during the last years a considerable portion has been used up without doubt by quality selection needs.

4. Priorities in future rapeseed developments

This directly leads to the question of future priorities in rapeseed developments. With due regard to the immediate interests of the producers, this means the breeders and farmers, and in view of the given demand by the customers on the other side, priority ranking to my understanding should read as follows:

1. Securing production and consumption at the present 00-quality level;
2. Improving actual 00-rapeseed quality for the ready uses as food/feed;
3. Developing new rapeseed genotypes for additional applications.

Securing the production in the established 00-quality has the absolute first priority for stabilizing the consumption of the rapeseed commodity in the world market. This goal is by no means trivial and requires the combined efforts of research, industry and market management.

The situation at the research level may be visualized with the example of a current EU Concerted Action of Research, in which the Quality Group is coordinated by Dr. A.E. Arthur from Norwich, U.K. (**Table 6**). These experts summarized a list of essentials for a high quality rapeseed production. They felt that the agronomist needs to know more on the environmental factors influencing rapeseed quality, e.g. fertilizer treatment or disease incidences. Volunteers are another particular problem in rapeseed, particularly in times of quality changes of production.

Oil percent is an important goal in addition to grain yield increase *via* hybrid cultivars, to improve the economic profitability of high quality rapeseed productions. In Canada, herbicide tolerance minimizing volunteer problems is expected to contribute to an additional improvement of quality levels in Canadian Canola seed exports.

For the topic of raising specific fatty acids we today ascribe priority to higher oleic acid concentrations. As reported, high oleic acid rapeseed oil is demanded in the food market and likewise for oleochemicals and for biodiesel (RME) productions. The first step in this direction has already been done with the change towards zero erucic types raising the oleic acid content of the rapeseed oil from an average of 38 % to about 60 %. It may be discussed whether continuation in this direction should finally arrive at a high oleic acid rapeseed oil as the general commodity standard or whether this should further be treated as a specialty oil. Mrs. Dr. Trautwein may meditate on this question later during this symposium.

For the rapeseed meal, Prof. Henkel may outline similar trends. I am sure that he as an animal nutritionist could easily pose a dozen of wishes for improved meal quality. But I am also convinced that by careful application of the presently possible 00-cultivars, rapeseed meal can be produced, which will readily disappear in feed consumptions. On the other side, the agronomist may be interested to know more on possible interactions of the low glucosinolate content with production parameters, such as the known low sulfur use efficiency of the 00-cultivars or possible effects of these and other secondary plant substances (lectines, phytate and others) on for example resistance reactions against pathogenic fungi or nematodes; *vice versa* the feasibility of using glucosinolates for pharmaceuticals or crop protection is also discussed at present.

The potential of rapeseed for new quality products is almost unlimited if regarded from the technical point of view, this is availability of analytical methods or of biotechnological options. However, the present European productions suffer severely from political handicaps (**Table 7**). Because of the GATT restrictions farmers are forced into extensive non-food productions of rapeseed. But these, whether for oleochemicals or for biodiesel still lack established consumptions. Biodiesel, for example, which has been promoted as another outlet for rapeseed harvests, will remain a specialty within the fuel market, with applications to environmentally sensitive areas, but also with all the problems inherent in small niche markets. Confidence of farmers and industry in these uses is largely insufficient to base on it solid investments. What was started for stabilizing rapeseed productions, remains a permanent act of balancing on a tightrope, which is not at all leading into a reliable future.

Summary

1. Zero erucic rapeseed oil (Canola) belongs to the most healthy dietary oils for human food consumptions. Its demand is increasing worldwide and therefore its production should be shared by all regions, which can contribute to the required world supplies.

2. Further improvements of rapeseed oil quality within the present standards towards lower linolenic as well as higher oleic acid contents are suited to effectively threngthen the existing marketing pathways.

3. For feed uses of the coproduced rapeseed meal, the 00-Canola standard with a maximum of 12 umol/g sets the mark for todays' international trades and must be obeyed with European productions in the long run, too.

4. Hybrid cultivars as they are emerging at present are the most timely chance of producing attractive amounts of rapeseed in the high quality, which has been set up during the previous 3 decades of quality breeding.

5. Larger quantities of rapeseed oil are well applicable for technical and energetic uses without new quality properties; such uses contribute to stabilize rapeseed productions under fluctuating world market conditions.

6. Modern breeding technologies allow an almost unlimited development of new quality traits in rapeseed for high value uses. But different from the food sector, special investments in non-food productions are particularly risky and on the average these applications have to do with niche markets which are highly dependent on short-dated profitability.

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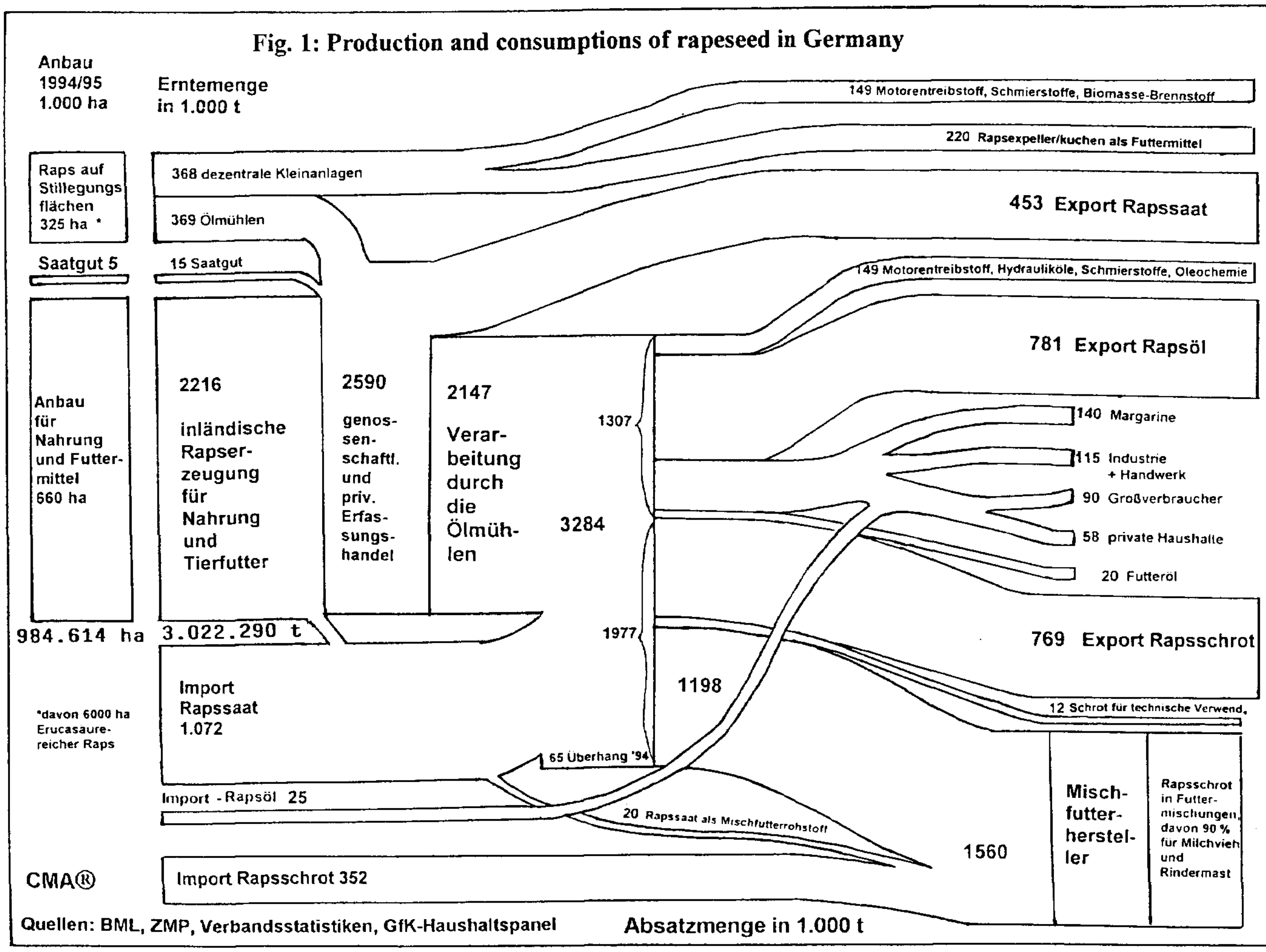


Fig. 1: Production and consumptions of rapeseed in Germany

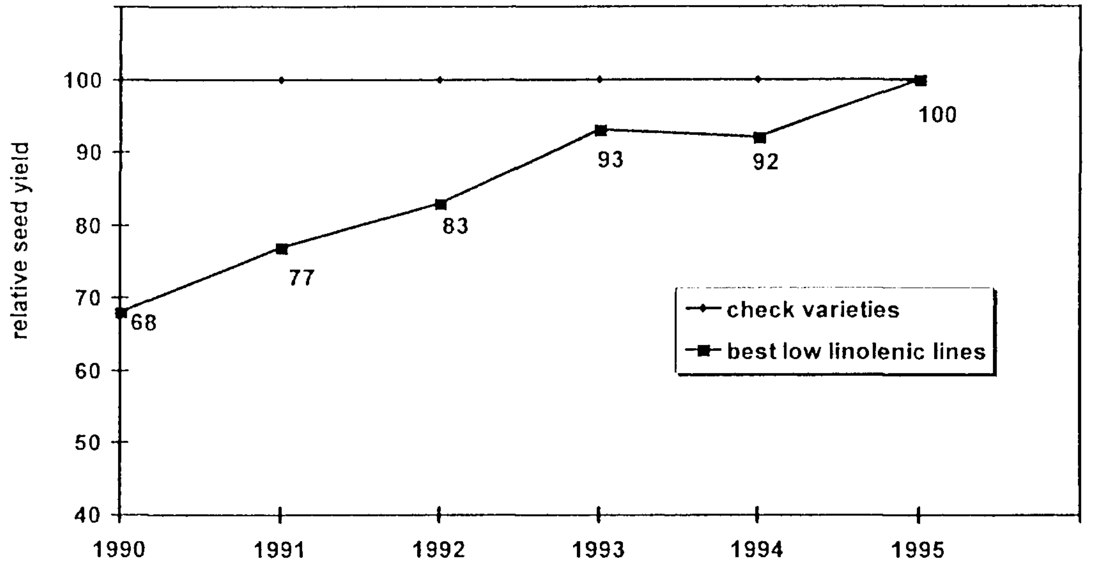
TABLE I

FATTY ACID COMPOSITION OF VARIOUS RAPESEED OILS

	B. campestris		B. napus	
	Echo Type	Zero-Erucic	Target Type	Zero-Erucic
$C_{16:0}$	3	4	3	4
$C_{16:1}$	0.1	-	0.2	0.2
$C_{18:0}$	1	1	1	2
$C_{18:1}$	37	55	22	67
$C_{18:2}$	18	31	15	20
$C_{18:3}$	8	10	8	9
$C_{20:0}$	0.4	-	0.5	0.5
$C_{20:1}$	10	-	12	1
$C_{22:1}$	23	-	39	0.5

Source: B. Weinberg - Further data on the processing of Canbra oil and its utilization in the manufacture of some shortenings and margarines. Proc. Int.Conf. Ste-Adèle, Sept. 20-23, 1970. 357-368

Fig. 2: Yields of best low linolenic lines in successive backcross generations



from: Rucker and Röbbelen (1996)

Table 2: Fatty acid composition of different rapeseed genotypes

Genotype	Fatty acid composition (%) of total seedoil 16:0	18:0	18:1	18:2	18:3	20:1	22:1
High erucic	4.5	1.5	15.5	13.0	10.0	6.0	50.0
Low erucic	4.5	1.2	60.0	22.0	12.0	0.1	0.2
Low linolenic	4.5	1.2	60.8	28.5	2.3	0.1	0.2
High oleic	4.5	1.2	75.0	16.0	3.0	0.1	0.2

Table 3: Increment value of breeding success in rapeseed

	1975	1985	1990	1995	1996	1985 -1996
1 Soybean oil fob ($ / t)	551	501	446	625	554	
2 Rapeseed oil fob ($ / t)	517	462	420	614	556	
3 Price difference	-34	-39	-26	-11	2	
4 Deviation ($ / t) (line 3)			13	15	13	
5 Rapeseed oil production (1,000 t / a)			2300	3005	3170	
6 Increment value (mio $ / unit time) lines 3x5			150	225	41	**416**

Source: Brauer 1997 (calculated from ZMP data)

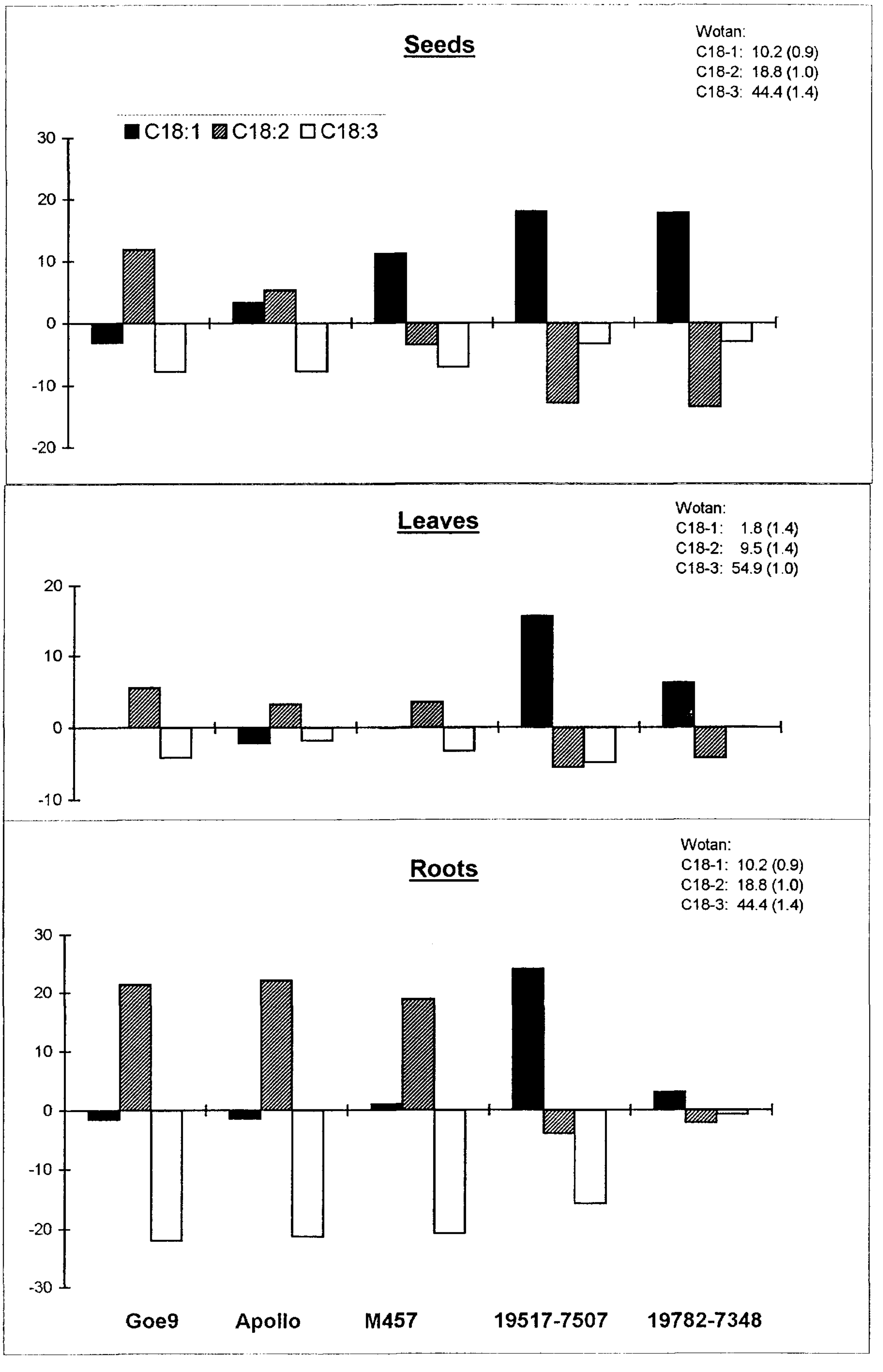


Fig. 3: Fatty acid composition (%) of total lipids in mutant tissues plotted as difference to control cv. 'Wotan' (=0) (Rücker & Röbbelen 1996)

Fig. 4:
Entwicklung der Ertragsleistung (rel.) der wichtigsten Winterkörnerraps-Sorten in Deutschland

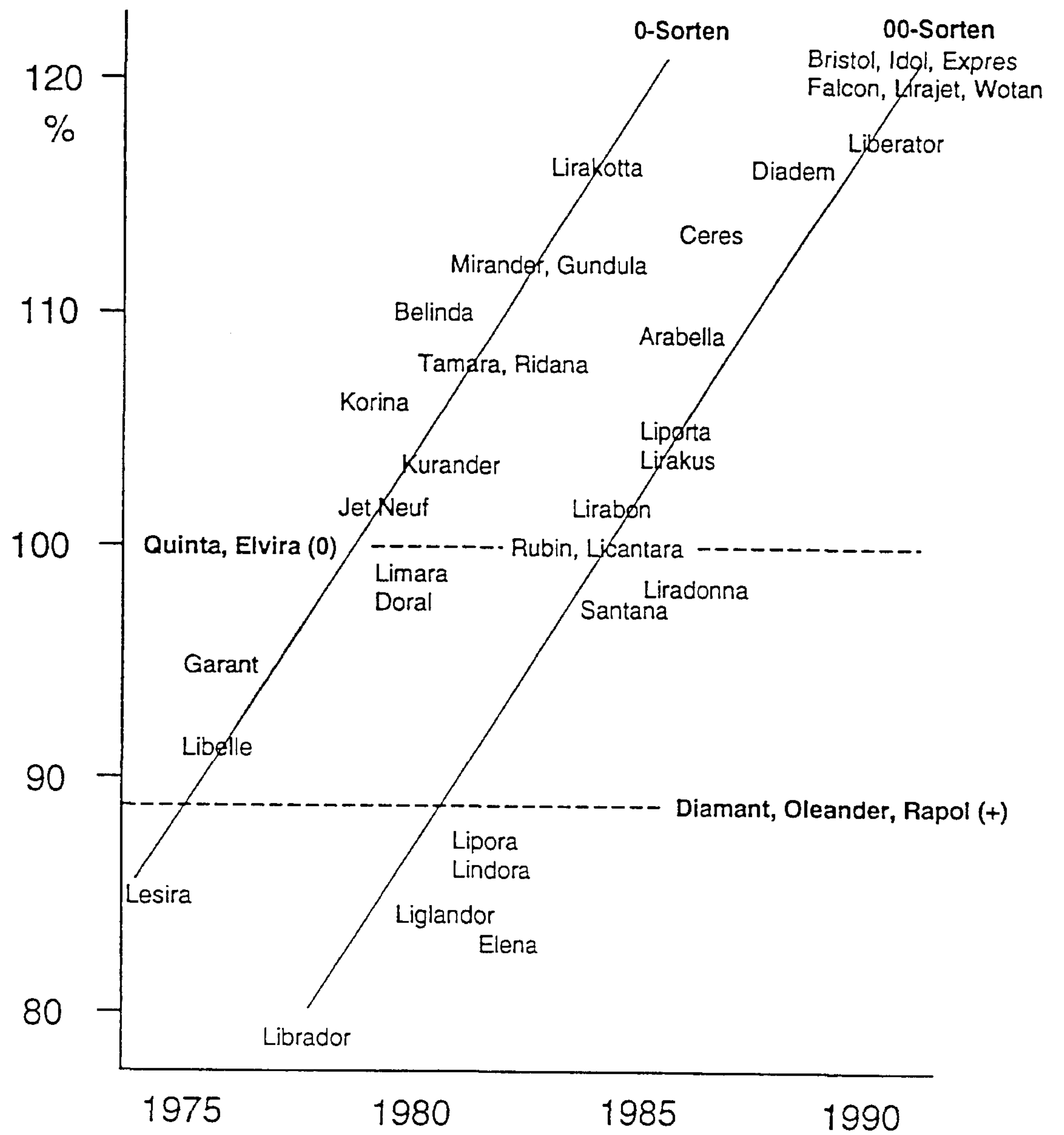
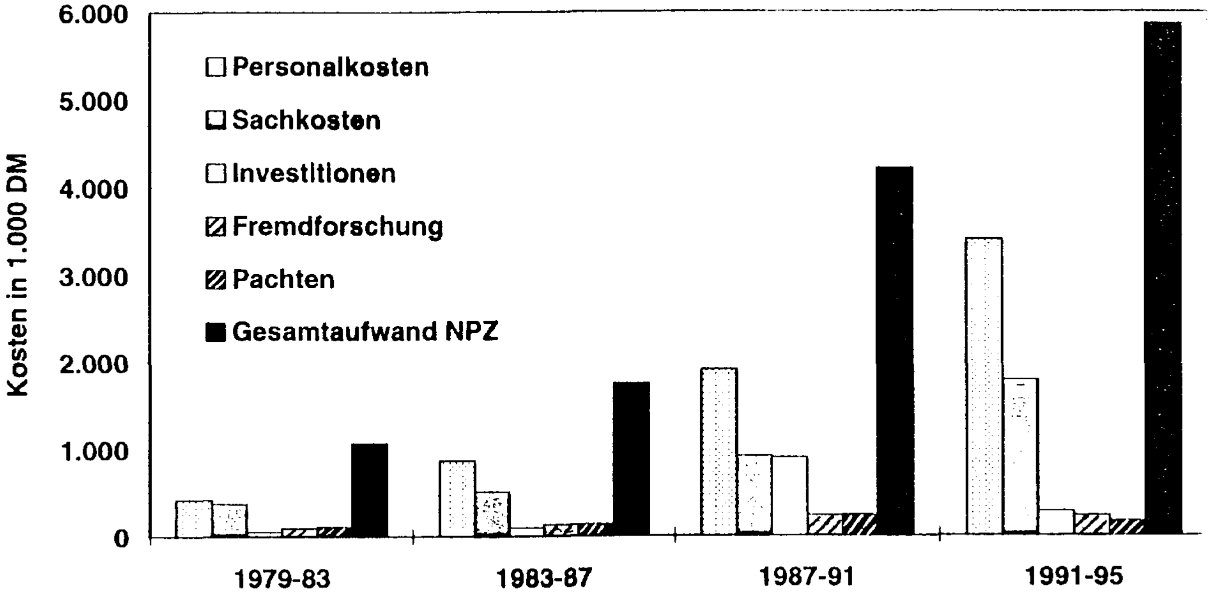


Table 4: Production of rapeseed meal in the EU (in 1000 t)

1965	1970	1975	1980	**1985**	**1990**	**1994**
266	380	562	1360	**2473**	**3779**	**3698**

Source: Fediol Statistiques, 1970 - 1995

Fig. 5: **Zunahme der jährlichen Züchtungskosten von 1979 - 1995 am Beispiel der Norddeutschen Pflanzenzucht**



Quelle: NPZ, 1996

Table 5: Seed yield in F4 lines raised after yield only (Y) *vs* quality selection (Q) in winterrape (Sauermann 1988)

	Mean yield of lines		
	all selected ones		3 best ones
	dt/ha	rel %	rel %
Parental mean	40.9	100	100
Quality selection (Q)	41.2	101	105
Yield selection (Y)	44.9	110	114
Difference Y - Q	3.7**	9.1**	9.0**

Table 6: Research areas of the EU Concerted Action project AIR 3 CT 94 2231, Quality group (modified)

1. Influence of agronomy and environment on oilseed quality
   - Latitude / day length
   - Temperature / drought
   - Fertilizer
   - Disease
2. Volunteers
   - Pod shattering
   - Dormancy / seed longevity in the soil
   - Harvesting methods
3. Oil quality requirements
   - Raising oil content to 55 %
   - Transgenic herbicide tolerance and oil quality
   - Impact of raising specific fatty acids on commercial potential
4. Meal quality requirements
   - Glucosinolate levels in the seed
   - Anti-nutritional properties of glucosinolates
   - Impact of low glucosinolate in the vegetation
   - Uses of extracted glucosinolates
   - Lectins and other anti-nutritionals
   - Fiber digestibility
5. Rapid quality estimation
   - Near infrared (NIR)
   - Use of genetic markers
6. Policy and marketing
   - GATT and blair house treaty
   - Education and public perception
   - Biodiesel
   - Transgenics
7. Quality aspects for the future
   - Genetic engineering of quality factors
   - Suppressing of outcrossing
   - Protein quality and seed processing

Table 7: Rapeseed production (in 1000 ha) in Germany (UFOP)

	Total	Non-Food uses	Difference (food)
1993	1,007	61	936
1994	1,057	136	915
1995	985	337	648
1996	921	283	629