HGCA

PROJECT REPORT No. OS33

# EFFECTS OF DISEASE ON SEED QUALITY PARAMETERS OF OILSEED RAPE GROWN FOR INDUSTRIAL USES

OCTOBER 1998

Price £4.00

PROJECT REPORT No. OS33

# EFFECTS OF DISEASE ON SEED QUALITY PARAMETERS OF OILSEED RAPE GROWN FOR INDUSTRIAL USES

by

K J DOUGHTY[1], G NORTON[2], G LANDON[1], G WEST[2],
H A McCARTNEY[1], E J BOOTH[3], K C WALKER[3],
S P J KIGHTLEY[4], and J E THOMAS[4]

[1] IACR-Rothamsted, Harpenden, Hertfordshire AL5 2JQ
[2] University of Nottingham, Sutton Bonington Campus, Loughborough LE12 5RD
[3] Scottish Agricultural College, Craibstone Estate, Bucksburn, Aberdeen AB21 9YA
[4] National Institute of Agricultural Botany, Huntingdon Road, Cambridge CB3 0LE

This is the final report of an eighteen month project which started in July 1995. The work was funded by a grant of £72,090 from the Home-Grown Cereals Authority (Project no. OS11/1/94).

CONTENTS Page Nos.


1: SUMMARY 2

2: INTRODUCTION 4
2.1: Rapeseed and its uses. 4
2.2: Aspects of seed quality. 4
2.3: Diseases of oilseed rape and their importance. 5
2.4: Rationale and Objectives. 5
2.5: Approach. 6

3: MATERIALS AND METHODS 7
3.1: Experiments in 1994-5. 7
3.2: Experiments in 1995-6. 7
3.3 : Analysis of seed samples. 8
3.3.1: Thousand seed weight. 8
3.3.2: Oil content. 8
3.3.3: Fatty acid composition. 8
3.3.4: Molecular species composition. 9
3.3.5: Protein content. 9
3.3.6: Chlorophyll content. 9
3.3.7: Acid value. 9
3.3.8: Peroxide value. 9
3.4: Statistical analysis. 9

4: RESULTS 10
4.1: Disease incidence. 10
4.2: Seed dry matter yield, oil content, thousand seed weight and protein content. 14
4.3: Oil fatty acid composition, group separations and molecular species pattern. 20
4.4: Levels of contaminants in the oil. 28

5: DISCUSSION 33
5.1: Oil content. 33
5.2: Protein content. 33
5.3: Fatty acid composition. 33
5.4: Contaminants. 34
$.5: Implications 35

6: CONCLUSIONS 36

7. ACKNOWLEDGEMENTS 37

8: REFERENCES 38

9: APPENDIX I 41

## 1: SUMMARY

Oilseed rape (*Brassica napus* L.) produces an oil that is currently used mainly for human consumption but also, on a smaller scale, for industrial applications. There is great potential for the industrial use of rape oil to expand, and special cultivars are being bred to produce oils specifically suited to a particular application. Rape crops are required to produce seed containing as high a content as possible of oil with a fatty acid composition that is optimal for the intended end-use. Conversely, the seed should contain the lowest possible levels of contaminants that increase processing costs.

Financial returns to the farmer growing either type of crop are currently marginal, meaning that there are economic constraints on the inputs that can be made to the crop. Among inputs, fungicide applications are often targets for saving. However, the fungal diseases that develop more freely in the absence of fungicides can have profound effects on the yield and physiology, and possibly on the quality of the crop. This study investigated how fungal disease affects rape seed composition in order to indicate the importance of crop protection for maintaining quality. Our aim was to provide information that could be used to predict the crop protection needs and also in cost-benefit analyses of fungicide use in contemporary crops, and perhaps the economic viability, of future, high-value specialist-oil crops.

Seed samples of various double-low and industrial winter and spring rape cultivars were taken from experiments at IACR-Rothamsted and from variety trials plots coordinated by the National Institute of Agricultural Botany (Cambridge) and the Scottish Agricultural College (Aberdeen) in 1994-5, and at Aberdeen, Brampton, Bridgets, Edinburgh and Morley in 1995-6. Plots were either: (i) treated with fungicides to control disease, or (ii) inoculated or left untreated to encourage disease. Seed samples were analysed for selected indicators of quality at the University of Nottingham. The indicators were selected as representing: those factors that contribute to the yield of end-products (seed oil content, oil fatty acid composition, group separation, molecular species pattern, and seed protein content); and those factors that devalue the seed by increasing processing costs (chlorophyll content; acid value and peroxide value). The results were as follows:

• *Seed dry matter and oil content*: Infection usually decreased oil content in disease susceptible winter and spring double-low varieties, but less so in high erucic acid varieties. Because disease also tended to decrease dry matter yield, oil yield was further decreased in double-low varieties. Oil yield was reduced by up to 30% in susceptible varieties when levels of infection were severe. In some experiments, oil content was directly related to the incidence of a single, predominant disease. In contrast, HEAR cultivars often showed no such overall decrease in oil content as the result of infection.

• *Oil fatty acid composition, group separation and molecular species pattern*: Severe infection caused significant qualitative and quantitative changes in oil fatty acid composition. The changes were generally greater among cultivars that had suffered the greatest loss in oil content in unprotected plots. However, the changes differed in each type of cultivar, and according to the predominant pathogen. Unprotected plots of double-low cultivars generally produced oil with more [18:2] and [18:3] fatty acids, at the expense of [18:1], but the proportion of palmitic [16:0] and stearic [18:0] acids in the oil was generally unchanged by severe infection. In one experiment in 1994-5, severe stem rot (caused by *Sclerotinia sclerotiorum*) introduced the otherwise-absent hexadecatrienoic [16:3] and erucic [22:1] acids into the oil of a double-low cultivar. Disease generally decreased the triacylglycerol (TAG) fraction of the oil, but increased the diacylglycerol

fraction. Analysis of TAG molecular species patterns showed that disease increased the proportion of species rich in polyunsaturated fatty acids at the expense of monounsaturated fatty acids. These changes were, generally, but not exclusively, deleterious for food-use crops.

The fatty acid composition of the oil of HEAR cultivars usually changed as the result of infection, but without an overall uniformity of change. In some cases, the proportion of eicosenoic [20:1] and erucic [22:1] acids was higher in oil from unprotected plots at the expense of 18-Carbon fatty acids.

• *Seed protein content:* seed from heavily-infected plots of double-low cultivars usually had higher protein contents, but seed from heavily-infected plots of HEAR cultivars had lower protein contents than that from corresponding fungicide-treated plots. In double-low cultivars the decrease in oil content tended to equal the increase in protein content suggesting that disease affected both processes in equal but opposite ways.

• *Contaminants of the oil (chlorophyll, free fatty acids and peroxides)*: Severe disease tended to affect chlorophyll content, but the direction of the change varied between sites and seasons. Seed from heavily-infected plots showed no consistent changes in acid value or peroxide value.

• *Phytotonic effect of fungicides*: Fungicide treated plots tended to have higher oil yields even when disease levels were low, implying that spray treatments could affect crop growth independent of disease.

Our results indicate that diseases can be significant determinants of the oil quality of seed via their effect on the yield of a particular, desirable fatty acid. The loss in oil content in seed from unprotected crops may endanger the saleability of the crop. The increase in protein content in seed from unprotected plots does not offset the loss in oil content, because the meal is much less valuable than the oil. The implications of the effects of disease on seed quality detected in this study are complex. In particular the importance of the changes in fatty acid composition in unprotected plots depends on the use intended for the oil. The general pattern of a shift towards longer-chain unsaturated fatty acids in heavily-infected plots suggests that some industrial cultivars will be more vulnerable to losses in quality when unprotected than others, depending on the required fatty acid spectrum. The increase in the proportion of erucic acid [22:1] in the oil of diseased HEAR plots in some experiments represented an improvement in quality, although the loss in seed dry matter yield offset this ostensible advantage of withholding fungicides. In contrast, the appearance of erucic acid [22:1] in the oil from stem rot-infected crops would be particularly undesirable for food-use. The effects of diseases cannot be generalised, because changes in both oil content and fatty acid composition differ according to the predominant pathogen.

Considered together, our results suggest that controlling diseases will be important if growers are to provide processors consistently with seed of the required quality from crops. They also suggest that unless it is possible to incorporate durable varietal resistance into future, high-value industrial rape cultivars, fungicides are likely to play an important role in their agronomy.

## 2: INTRODUCTION

### 2.1: *Rapeseed and its uses.*

Winter oilseed rape (*Brassica napus* L.) is an important break-crop in the UK. The major product from the seed is the oil, although the meal that remains when the oil has been extracted is a source of protein for animal feed. In recent years, double-low (low erucic acid, low glucosinolate) rape has been grown mainly for the production of oil for use as cooking oil and an ingredient in margarine and a wide range of other food products. But there is now increasing interest in using rape oil for a number of industrial applications: as a fuel oil (biodiesel); to produce lubricants and surfactants; or as a feedstock for the extraction of particular fatty acids. Biodiesel provides the largest industrial market for the double-low crop in Europe, although rapeseed oil is not processed into biodiesel in the UK. The markets for erucic acid and its derivative behenic acid from the high erucic acid (HEAR) crop are well established and these products are used in a number of industries (Sonntag, 1995). In 1994-5, an estimated 87,000 ha of industrial rape was grown on set-aside in the UK, approximately 85% of which was double-low rape (for biofuel) and 15% high erucic acid rape (Askew, 1995). However, genetic engineering promises various 'customised' rape varieties in the future, each with the potential to produce a high-value oil with a fatty acid composition suited to a specific set of applications. Considerable breeding effort is in progress to produce these varieties.

Industrial rape crops have environmental advantages over alternative mineral oil sources of raw materials that range from carbon cycling (when used as a source of biofuel) to the biodegradability of their products (when used in lubricants and surfactants). Conditions in the UK are suitable for growing industrial rape crops. However, factors such as contracts offered for industrial crops, the competitiveness of other crops and the availability of set-aside land has meant that industrial crops have been grown mainly on set-aside.

### 2.2: *Aspects of seed quality.*

Ideally, rape seed should have the highest possible oil content, and the meal should have the highest possible protein content, although premiums for the latter are not currently available. Within the oil, the most valuable components (constituting about 90%) are the fatty acid-containing triacylglycerols (TAG). The balance and spectrum of the fatty acids contained in TAG are important aspects of quality. Recent research suggests that oils which are rich in monounstaurated fatty acids are beneficial for health compared with other oils (McDonald *et al*, 1989). Rape seed oil is considered to be well suited for use in foodstuffs: it contains a high level of the monounstaurated fatty acid oleic acid [18:1] (which has anti-cholesterol properties, and which confers stability and good frying quality); the essential fatty acids linoleic [18:2] and linolenic acid [18:3], in the proportion that is appropriate for nutritional quality and stability in storage; the lowest levels of saturated fatty acids of commonly used vegetable oils; and low erucic acid [22:1], which is deleterious to health (Ackman, 1990). In contrast, HEAR crops are required to produce seed with the highest possible content of erucic acid, and some of the cultivars currently being bred for other, specific industrial uses are also likely to require the highest possible concentration of a single fatty acid.

Some of the lesser components of the oil are undesirable for many applications. For example, excessive concentrations of free fatty acids, which can decrease the oil's shelf-life, have to be removed during processing, thereby increasing processing costs. Thus the 'acid value' of the oil (which reflects free fatty acid content) should be as low as possible. Similarly, hydroperoxides

(oxidation products of polyunsaturated fatty acids, particularly 18:2 and 18:3 ) are undesirable in the oil because they can affect odour and flavour. Refined oils are very susceptible to oxidation, because antioxidants are removed during processing: thus the 'peroxide value' (which reflects hydroperoxide content) of the oil should also be as low as possible (Harwysh, 1990).

Some lipid-soluble compounds that are co-extracted in the oil must also be removed during processing because they impart undesirable properties to the oil. For example, chlorophylls colour the oil, reduce its stability, affect its flavour, increase its tendency to rancidity, and interfere with the industrial hydrogenation of the oil, necessitating the use of bleaching agents to remove them. Chlorophylls are costly to extract and therefore seed lots containing high concentrations may be downgraded by processors on the basis of 'green seed counts' (Daun, 1995; Uppström, 1995).

2.3: *Diseases of oilseed rape and their importance.*

Oilseed rape is subject to several fungal diseases. In the UK those most commonly associated with yield losses are: light leaf and pod spot *(Pyrenopeziza brassicae)*; phoma canker (*Leptosphaeria maculans*); sclerotinia stem rot (*Sclerotinia sclerotiorum*); and alternaria dark leaf and pod spot (*Alternaria brassicae* and *A. brassicicola*), although their relative importance differs regionally. The leaf and pod spots probably affect yield mainly by limiting photosynthesis in developing pods; the other diseases by interfering with nutrient uptake, and by weakening plants structurally, thereby causing lodging and premature senescence. Fungicide treatments to rape are most often applied during the period from early stem-extension to early pod-development, with the intention of limiting the spread of inoculum to pods and stems. Although more attention is being given to autumn sprays, particularly for stem canker control.

Oilseed rape can be vulnerable to yield losses under conditions of reduced fungicide applications (Bowerman *et al.*, 1994). Fungicides are often effective in preventing damaging infections, but applications sometimes fail to give economic returns on conventional rape in terms of dry matter yield (Jordan and Hutcheon, 1994). In some seasons, seed dry matter oil content can also be lower in unprotected crops compared with fungicide-treated crops (Rawlinson *et al.*, 1989, Sweet *et al.*, 1989) but little is known of the effects of fungal diseases on the quality of the seed. The effects of diseases on the physiology of the crop (including flowering time, pod distribution within the canopy, and rate of seed maturation) suggests that they are likely to influence seed quality (Doughty *et al.*, 1995). Reductions in seed quality with respect to glucosinolate concentration have been reported (Bock *et al.*, 1991).

2.4: *Rationale and objectives.*

Current economic constraints on the use of fungicides on rape coincide with the perceived environmental benefits of low input crop-protection systems, especially on set-aside. Thus the future economic viability of both food-use and industrial crops probably depends on farmers' ability to provide, consistently, a supply of oil of the composition and quality required by processors, but without incurring excessive costs and adverse environmental impact in doing so. Given that there is a lack of information on how rape seed quality is affected by fungal disease, we have sought to identify the potential problems associated with growing rape without fungicides. The objective of this study was to assess the effects of disease on oil yield and quality of conventional double-low and industrial crops at different sites in the UK. This information is needed to asses the potential requirements for fungicide used on industrial rape crops and on future, specialist-oil varieties.

2.5: *Approach.*

The approach employed was to identify a set of indicators of seed quality, including those associated with the yield of useful products (oil content, oil fatty acid composition, molecular species composition and protein content) and those associated with increased costs to processors (chlorophyll content, acid value and peroxide value), and to investigate how each is affected by disease. In two seasons (1994-5 and 1995-6), experiments were done that involved fungicide-treated and -untreated plots, or plots that were inoculated with specific pathogens or with mixtures of pathogens. The progress of diseases in the plots was monitored, and the harvested seed analysed for quality. The experiments involved winter and spring cultivars, including conventionally-bred double-low, HEAR and other specialist fatty acid types, and the winter hybrid varietal association *Synergy*. Experiments were situated at a number of sites throughout the UK, to investigate the relative importance of disease and environment as determinants of seed quality. In discussing our results, 'disease' is used as a collective term, except where the incidence of a specific, predominant pathogen was shown to be important.

## 3: MATERIALS AND METHODS

Seed samples were collected from field experiments in 1994-5 and 1995-6. In most experiments, treatments were applied as follows: fungicide-treated (F); inoculated (I) or untreated (U). F-programmes were usually prophylactic, comprising three sprays (in autumn, spring and summer) designed to provide treated plots with protection from disease for as long as possible. When used, inoculation (I) was done by applying contaminated rape straw (retained from a recently-harvested, heavily-diseased crop) to plots early in the season. Untreated plots received neither fungicides nor applied inoculum, but they were exposed to background inoculum. All other agronomic factors were common to each treatment.

### 3.1: *Experiments in 1994-5.*

Three winter-rape experiments were done at IACR-Rothamsted (Table 3.1.1). In the first, two conventional, double-low cultivars (*Capricorn* and *Falcon*) were grown in F and I plots. These cultivars were chosen because they were known from previous work to differ in their susceptibility to light leaf and pod spot and dark leaf and pod spot and to differ in their relative vulnerability to losses in yield and oil content following infection (Doughty *et al.*, 1995). In the second experiment, the HEAR cultivar *Askari* was grown on set-aside land in F and I plots. In the third experiment, a plot of the double-low cultivar *Apex* was used as a source of sclerotinia-infected and -uninfected plants, collected by hand immediately before combine harvest. The 'infected' plants were selected to represent severe infection, in which the stem of the plant is girdled by the disease. One winter-rape experiment was done at Aberdeen (Table 3.1.1), in which 18 double-low cultivars were grown in F and U plots. Dry matter yield was measured at experiments at Rothamsted only.

Table 3.1.1: Varieties used in experiments in 1994-5.

| Site | Varieties | Treatments |
|---|---|---|
| Rothamsted | Capricorn, Falcon (DL) | F and I |
| Rothamsted | Askari (HEAR) | F and I |
| Rothamsted | Apex (DL) | Selection of sclerotinia - infected or -uninfected plants |
| SAC- Aberdeen | Alaska, Amber, Apex, Bristol, Cannon, Commanche, Envol, Express, Falcon, Gazelle, Hansen, Idol, Inca, Mandarin, Nickel, Rapier, Rocket, Tomahawk | F and U |

DL - double-low; HEAR- high erucic acid rape

### 3.2: *Experiments in 1995-6.*

Experiments in 1995-96 incorporated a greater number of varieties, including both winter and spring types, at more sites. Emphasis was also placed on industrial cultivars other than HEARs, these were all spring types. A varietal association (*Synergy*) was also tested.

There were four winter-rape experiments. At Aberdeen, fourteen double-low cultivars (including the varietal association, *Synergy*) and two HEAR cultivars were grown in F and U plots (Table 3.2.1). A sub-set consisting of five of these cultivars (*Synergy, Bristol, Nickel* [double-low], *Askari* and *Martina* [HEAR]) was also grown in F and U plots at each of three further sites (Brampton, Bridgets and Morley) to investigate the relative importance of disease and environment as determinants of oil quality. In addition, the cultivar *Express* was grown at the Bridgets site.

There were two spring-rape experiments. At Aberdeen and Edinburgh, three double-low cultivars (*Starlight, Mars and Global*) were grown alongside the HEAR cultivar *Industry* and the high oleic acid cultivar *Hyola 401* in F and U plots. Sclerotinia-infected and -uninfected plants were also selected from a commercial field of *Hyola 401*.

Table 3.2.1: Winter rape varieties used at Aberdeen in experiments in 1995-6.

| Double-low | HEAR |
|---|---|
| Bristol, Corporal, Ecuador, Envol, Express, Falcon, Gazelle, Inca, Jazz, Lizard, Mandarin, Nickel, Rapier, Synergy | Askari and Martina |

3.3: *Analysis of seed samples.*

All seed samples were cleaned to remove chaff and weed seeds before analysis. Samples destined for analysis of thousand seed weight were dried at 105°C for 24 hours. Those destined for other analyses were dried at 45°C for 24 hours before storage. Analyses of oil content and thousand seed weight were carried out on all samples within an experiment; subsequent analyses were usually done on fewer samples, representing cultivars that showed the greatest difference in these parameters. All analyses were done at least in duplicate. Brief details of the preparation of samples for each analysis are given below.

3.3.1: *Thousand seed weight.*

Estimates of thousand seed weight (TSW) were obtained by counting the number of seeds in a 5g sample, then drying it at 105°C, reweighing, and calculating from these data. Selected samples were also graded according to diameter.

3.3.2: *Oil content*

Seed oil content was estimated using a modified Soxhlet extraction method (BS 4289: Part 4, 1989). The method involved a standard Soxhlet extraction of the ground rapeseed meal with petroleum ether for 8 hours. The extracted meal was ground in a pestle and mortar, quantitatively transferred back to the Soxhlet thimble and re-extracted with petroleum ether for a further 2 hours. The process was repeated again. The petroleum ether extracts were combined, the solvent evaporated as in the standard method and oil dry weight determined.

3.3.3: *Fatty acid composition.*

Fatty acid composition was determined by gas chromatography of fatty acid methyl esters following the methyl esterification of the oil. Data for individual fatty acids are expressed as the percentage of mass fatty acid composition. The common names of the fatty acids determined in the analyses are given in Appendix 1.

3.3.4: *Molecular species composition.*

Seed samples of two cultivars from the 1994-5 experiment at Aberdeen were selected for molecular species composition analysis. The cultivars represented the largest and smallest differences in oil fatty acid composition between F and U plots.

3.3.5: *Protein content.*

The total nitrogen content of the seed meal was determined by an automated Kjeldahl procedure. The protein content was the estimated as the nitrogen content x 5.67.

3.3.6: *Chlorophyll content.*

The standard method for chlorophyll extraction (BS 4289: Part 10, 1992) proved unsuitable for the routine estimation of chlorophyll in rapeseed. The following procedure was found to be highly reproducible and was used for all the analyses. Briefly, 5g of ground seed plus a small amount $MgCO_3$ was homogenised with 30ml $CHCl_3$/MeOH (2:1 v/v) and left for 15min. The suspension was filtered and the residue re-extracted as before. The filtrates were combined and the absorbance read at 643 and 660nm and the chlorophyll content estimated from the absorbance readings (total chlorophyll in mg $ml^{-1}$ = 7.12 x $A_{660}$ + 16.8 x $A_{643}$).

3.3.7: *Acid value.*

Free fatty acid content of the seed was determined by estimating the amount of potassium hydroxide required to neutralise a given mass of oil. The sample was titrated against potassium hydroxide, and phenolphthalein was used as an indicator. Data are expressed as the number of mg of potassium hydroxide required to neutralise 1g oil extract. (BS 4289: Part 5, 1989).

3.3.8: *Peroxide value.*

Seed peroxide value was determined by estimating the amount of substances that oxidise potassium iodide under defined conditions. Samples were dissolved in chloroform, then acetic acid was added, followed by potassium iodide. The amount of iodine liberated was estimated by titrating with sodium thiosulphate solution. Data are expressed as milliequivalents of active oxygen per kg of sample (BS 684: Section 2.14, 1987).

3.4: *Statistical analysis.*

Data from experiments involving replication were analysed by analysis of variance. For data from unreplicated experiments involving a number of cultivars, treatment (U and F) means were compared using a standard error that was estimated using the interaction term for cultivars and treatments. No statistical analyses were possible on the data from other experiments.

4: RESULTS

4.1: *Disease incidence.*

Disease in the winter oilseed rape experiments for the two season are summarised in Tables 4.1.1 to 4.1.7. In general, fungicide-treated (F) plots were never free of infection, but epidemics were generally later, and less severe in those plots than in untreated (U) plots, and much less severe than in inoculated (I) plots. Inoculation had the effect of encouraging disease, inducing earlier epidemics that culminated in more severe pod infection. But the effect was selective, favouring light leaf and pod spot and dark leaf and pod spot in particular. For example at Rothamsted the incidence of light leaf spot and dark pod spot was greater in I plots of *Capricorn* and *Falcon* (double-low), and *Askari* (HEAR) but dark pod spot in I plots was about four times that in F plots (Table 4.1.1 & .2). At Aberdeen in both seasons light leaf spot infection was lower in fungicide treated plots for all cultivars at all assessments with the exception of the cultivar *Nickel* at the April assessment when infection levels were similar (Table 4.1.3). Incidence of light leaf spot at Brampton, Bridgets and Morley was generally low in both untreated and sprayed plots. At Brampton and Bridgets stem canker was the predominant disease found (Tables 4.1.5 -6), but at Bridgets disease incidence was similar on untreated and treated plots.

Disease incidence in the spring rape experiments was extremely low in both sprayed and unsprayed plots.

Table 4.1.1: Disease incidence and severity (harvest) on double-low winter rape at Rothamsted, 1994-5.

| Cultivar | Light leaf spot | | | | Dark pod spot | | Stem canker | |
|---|---|---|---|---|---|---|---|---|
| | % pods infected | | Severity on stems (0-3 scale) | | % pods infected | | Severity on stems (0-6 scale) | |
| | F | I | F | I | F | I | F | I |
| Capricorn | 75.8 | 88.0 | 0.96 | 1.73 | 7.0 | 43.0 | 2.95 | 4.00 |
| Falcon | 73.5 | 90.8 | 1.62 | 2.06 | 10.3 | 48.5 | 3.85 | 4.10 |
| Mean | 81.9 | 89.4 | 1.29 | 1.90 | 8.65 | 45.75 | 3.40 | 4.05 |
| s.e.d. | 7.69 | | 0.122 | | 6.29 | | 0.404 | |

Table 4.1.2: Disease incidence and severity at harvest on winter HEAR at Rothamsted, 1994-5.

| Cultivar | Light pod spot % pods infected | | Dark pod spot % pods infected | |
|---|---|---|---|---|
| | F | I | F | I |
| Askari | 53.7 | 70.7 | 3.0 | 16.3 |
| s.e.d. | 7.20 | | 2.18 | |

Table 4.1.3: Disease incidence on double-low winter rape at Aberdeen, 1994-5.

| Cultivar | Light leaf spot incidence 21/4/95 | |
|---|---|---|
| | % infection | |
| | F | U |
| Alaska | 3.7 | 8.3 |
| Amber | 1.0 | 8.3 |
| Apex | 1.0 | 8.3 |
| Bristol | 6.7 | 23.3 |
| Cannon | 1.0 | 11.7 |
| Commanche | 5.0 | 11.7 |
| Envol | 6.7 | 25.0 |
| Express | 1.0 | 5.0 |
| Falcon | 5.0 | 16.7 |
| Gazelle | 3.7 | 16.7 |
| Hansen | 3.7 | 6.7 |
| Idol | 6.7 | 26.7 |
| Inca | 5.0 | 10.0 |
| Mandarin | 2.3 | 20.0 |
| Nickel | 2.3 | 8.3 |
| Rapier | 3.7 | 6.7 |
| Rocket | 5.0 | 10.0 |
| Tomahawk | 1.0 | 6.7 |
| Mean | 3.58 | 12.78 |
| s.e.d. | 1.335 | |

Table 4.1.4: Disease incidence on winter double-low (DL), HEAR and hybrid varietal association (HVA) crops at Aberdeen, 1995-6.

| Cultivar | Type | Light leaf spot (% leaves infected) | | | | | | Sclerotinia (% plants affected) 10/8/96 | |
|---|---|---|---|---|---|---|---|---|---|
| | | 25/4/96 | | 25/5/96 | | 19/7/96 | | | |
| | | F | U | F | U | F | U | F | U |
| Bristol | DL | 7.67 | 23.00 | 5.33 | 43.33 | 2.67 | 6.67 | 2.33 | 8.67 |
| Corporal | DL | 2.33 | 14.33 | 3.33 | 24.33 | 2.33 | 4.67 | 1.33 | 10.67 |
| Ecuador | DL | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| Envol | DL | 6.33 | 17.67 | 6.67 | 33.67 | 4.67 | 6.67 | 0.33 | 7.33 |
| Express | DL | 1.33 | 3.00 | 2.33 | 5.33 | 0.33 | 1.67 | 1.00 | 4.33 |
| Falcon | DL | 1.67 | 8.00 | 1.33 | 9.33 | 0.67 | 2.33 | 1.00 | 12.33 |
| Gazelle | DL | 1.00 | 5.00 | 2.67 | 7.00 | 0 | 2.00 | 1.00 | 4.67 |
| Inca | DL | 1.33 | 3.00 | 2.00 | 6.67 | 1.00 | 1.67 | 0.33 | 2.33 |
| Jazz | DL | 1.33 | 7.33 | 2.67 | 13.33 | 0 | 3.33 | 0.33 | 6.33 |
| Lizard | DL | 2.33 | 5.67 | 2.33 | 5.67 | 1.00 | 2.00 | 1.00 | 2.00 |
| Mandarin | DL | 2.00 | 12.67 | 3.33 | 30.00 | 1.00 | 6.00 | 1.67 | 12.67 |
| Nickel | DL | 2.33 | 2.33 | 2.33 | 5.67 | 0.67 | 1.67 | 1.00 | 2.33 |
| Rapier | DL | 1.33 | 3.33 | 2.33 | 7.33 | 0.67 | 2.00 | 1.00 | 5.33 |
| Synergy | HVA | 1.67 | 4.67 | 2.00 | 5.67 | 1.33 | 2.67 | 0.67 | 5.67 |
| Askari | HEAR | 0.67 | 9.00 | 1.33 | 5.00 | 0 | 5.00 | 0.33 | 2 |
| Martina | HEAR | 3.33 | 18.00 | 2.00 | 15.00 | 1.33 | 7.00 | 0.33 | 6.00 |
| Mean | | 2.44 | 9.13 | 2.80 | 14.49 | 1.18 | 3.77 | 1.16 | 6.18 |

Table 4.1.5: Disease incidence on winter double-low (DL), HEAR and hybrid varietal association (HVA) crops at Brampton, 1995-6.

| Cultivar | Type | Light leaf spot (% leaf area infected) | | | | Stem canker (0-100 index) | |
|---|---|---|---|---|---|---|---|
| | | F | U | F | U | F | U |
| | | - | 24/3/96 | 18/4/96 | 15/4/96 | 16/7/96 | 22/7/96 |
| Bristol | DL | n.d. | 3.0 | 5.7 | 5.0 | 26.8 | 53.3 |
| Nickel | DL | n.d. | 1.0 | 0.4 | 1.0 | 34.1 | 62.8 |
| Synergy | HVA | n.d. | 4.0 | 1.0 | 2.0 | 29.9 | 58.9 |
| Askari | HEAR | n.d. | 0.1 | 0.4 | 0.1 | 22.8 | 48.9 |
| Martina | HEAR | n.d. | 4.0 | 2.0 | 10.0 | 32.6 | 47.2 |
| Mean | | - | 2.4 | 2.3 | 3.6 | 29.2 | 54.2 |

Table 4.1.6: Disease incidence on winter double-low (DL), HEAR and hybrid varietal association (HVA) at Bridgets, 1995-6.

| Cultivar | Type | Light leaf spot (% leaves infected) | | Stem canker (0-100 index) | |
|---|---|---|---|---|---|
| | | F | U | F | U |
| | | 25/1/96 | 25/1/96 | 17/7/96 | 8/7/96 |
| Bristol | DL | 0 | 1.0 | 55.3 | 59.2 |
| Express | DL | 0 | n.d. | n.d. | n.d. |
| Nickel | DL | 0 | 0 | 46.7 | 63.2 |
| Synergy | HVA | 0 | 0 | 53.9 | 55.9 |
| Askari | HEAR | 0 | 0 | 45.0 | 47.9 |
| Martina | HEAR | 0 | 0 | 55.5 | 59.9 |
| Mean | | 0 | 0.2 | 51.3 | 57.2 |

Table 4.1.7: Disease incidence on winter double-low (DL), HEAR and hybrid varietal association (HVA) crops at Morley, 1995-6.

| Cultivar | Type | Light leaf spot (% leaf area infected) | | Stem canker (0-100 index) | |
|---|---|---|---|---|---|
| | | F | U | F | U |
| | | - | 24/4/96 | No external symptoms observed by first week in July 1996 | |
| Bristol | DL | n.d. | 0.7 | | |
| Nickel | DL | n.d. | 0.1 | | |
| Synergy | HVA | n.d. | 0.4 | | |
| Askari | HEAR | n.d. | 0.1 | | |
| Martina | HEAR | n.d. | 0.1 | | |
| Mean | | - | 0.3 | | |

4.2: *Seed dry matter yield, oil content, thousand seed weight and protein content.*

Seed dry matter yield, oil content, thousand seed weight and protein content for the winter and spring rape experiments are summarised in Tables 4.2.1 to 4.2.8.

Dry matter yield was generally lower in U or I plots than in F plots of winter varieties, although there was much variation between varieties and sites. For example at Rothamsted disease reduced yield more in *Capricorn* (25%) plots than in *Falcon* (9% ns). The reduction in yield in the HEAR cultivar *Askari* was similar to that for the susceptible cultivar *Capricorn* (mean values in the F plots were reduced by 23%, 2.71t $ha^{-1}$ to 2.07 t $ha^{-1}$ ). The yields for the spring experiments in 1995-6 were not determined.

In winter rape, disease appeared to affect seed oil content, but there were differences in this respect between double-low and HEAR cultivars. In 1994-5 and 1995-6, seed from U or I plots of winter and spring double-low cultivars (including the hybrid varietal association *Synergy*) usually had lower oil contents than corresponding F plots. In some experiments, the combination of lower dry matter yield and lower oil content led to substantial losses in oil yield in I or U plots, up to 30% in some of the susceptible varieties. In contrast, seed from HEAR cultivars in 1995-6 had no consistent pattern of difference in oil content between F and U plots. For example, for the four sites, cultivar *Martina* had a similar average oil content in F and U plots, whereas *Askari* had a higher average oil content in U plots.

The pattern of changes in oil content with fungicide use on winter double-low cultivars was consistent in the two seasons and at the various sites. However, the extent of the changes differed. For example, the difference in oil content between F and U plots at Aberdeen was greater in 1994-5 than in 1995-6. Furthermore, inter-site variation in oil content was greater than the difference between F and U plots for a given cultivar grown at a particular site. For example, in 1995-6 the maximum difference in oil content between F and U plots for *Synergy,* at a given site, was 3.2%, whereas for F plots oil content varied between sites from 39.5% to 44.7%.

The differences in oil content between U and F plots among spring cultivars was less consistent than for the winter types (Tables 4.2.7- 4.2.8). With one exception (*Mars*) all the F treated cultivars at Aberdeen had slightly higher oil contents than the U treatments. More variable responses were obtained from the Edinburgh trials.

Comparison of disease incidence with oil content suggests that where light leaf spot was predominant and severe, it could be a major factor in the loss in oil content suffered by a double-low cultivars if fungicides were withheld. In contrast, sclerotinia stem rot had relatively little impact on oil content: severely-infected plants of the winter cultivar *Apex* (Rothamsted, 1994-5) and the spring cultivar *Hyola 401* (Aberdeen, 1995-6) produced seed with an oil content similar to that from uninfected plants. The effects of disease at Brampton, Bridgets and Morley are more difficult to interpret. The incidence of light leaf spot was low at all sites but the incidence of stem canker varied between sites, while differences between yields and oil contents were consistent between the sites. The results from these sites suggest that there may have been a phytotonic effect of applying fungicides at these sites.

In general, TSW was reduced as a result of infection of susceptible winter varieties specifically at Aberdeen. Variable responses of TSW to infection were obtained with the winter rapes at the other sites and the spring rapes at both Edinburgh and Aberdeen.

Generally the protein content was higher in the seed from the U and I plots, but especially when infection with light leaf spot was severe on susceptible varieties. Protein content was also found to be consistently inversely related to oil content irrespective of treatment. In highly susceptible types with severe infection grown at Aberdeen in the 1994-5, protein quantitatively replaced the reduction in oil content.

Table 4.2.1: Seed dry matter yield, oil content and thousand seed weight in double-low winter rape at Rothamsted, 1994-5.

| Cultivar | Yield (t/ha @ 90% dry matter) | | Oil content (%) | | Thousand seed weight (g) | |
|---|---|---|---|---|---|---|
| | F | I | F | I | F | I |
| Capricorn | 3.63 | 2.71 | 42.5 | 40.8 | 5.193 | 4.648 |
| Falcon | 3.55 | 3.23 | 41.0 | 40.1 | 4.317 | 4.461 |
| s.e.d. | 0.324 | | 0.95 | | 0.3516 | |
| Mean | 3.59 | 2.97 | 41.8 | 40.4 | 4.755 | 4.554 |
| s.e.d. | 0.289 | | 0.86 | | 0.3071 | |

Table 4.2.2: Seed dry matter yield, oil content, thousand seed weight and protein content in double-low winter rape at Aberdeen, 1994-5.

| Cultivar | Yield (t/ha @ 90% D.M.) | | Oil content (%) | | Thousand seed weight (g) | | Protein content (%) | |
|---|---|---|---|---|---|---|---|---|
| | F | U | F | U | F | U | F | U |
| Alaska | 4.79 | 4.19 | 40.9 | 39.4 | 4.398 | 4.458 | 18.50 | 18.34 |
| Amber | 4.42 | 4.44 | 41.9 | 43.7 | 4.675 | 4.474 | 17.93 | 17.65 |
| Apex | 4.42 | 3.63 | 42.1 | 37.8 | 4.336 | 3.635 | 17.42 | 18.63 |
| Bristol | 3.39 | 2.57 | 41.5 | 38.1 | 3.581 | 3.480 | 18.13 | 19.85 |
| Cannon | 4.54 | 3.66 | 41.7 | 38.4 | 5.574 | 4.511 | 18.84 | 19.14 |
| Commanche | 4.79 | 4.29 | 45.3 | 42.3 | 4.570 | 4.184 | 17.79 | 17.59 |
| Envol | 3.72 | 2.78 | 40.6 | 35.1 | 3.819 | 3.064 | 18.96 | 21.22 |
| Express | 4.29 | 4.12 | 44.7 | 43.7 | 4.491 | 4.279 | 18.19 | 18.89 |
| Falcon | 4.62 | 4.51 | 40.5 | 39.1 | 3.885 | 4.173 | 18.03 | 18.35 |
| Gazelle | 4.87 | 4.19 | 35.4 | 34.4 | 4.550 | 4.213 | 18.02 | 18.66 |
| Hansen | 4.42 | 3.52 | 40.4 | 35.2 | 4.503 | 4.180 | 17.70 | 18.73 |
| Idol | 3.93 | 3.03 | 39.0 | 38.1 | 4.170 | 3.876 | 18.10 | 18.84 |
| Inca | 4.38 | 3.77 | 39.7 | 36.4 | 4.919 | 4.242 | 18.38 | 18.69 |
| Mandarin | 3.76 | 2.92 | 36.7 | 33.7 | 4.202 | 3.194 | 19.42 | 20.76 |
| Nickel | 5.03 | 4.47 | 44.1 | 42.5 | 4.495 | 4.627 | 17.50 | 17.59 |
| Rapier | 4.50 | 4.26 | 40.5 | 42.5 | 4.227 | 4.149 | 17.71 | 18.04 |
| Rocket | 4.05 | 4.12 | 39.9 | 40.2 | 4.286 | 4.096 | 18.77 | 18.77 |
| Tomahawk | 4.70 | 3.98 | 40.2 | 41.3 | 5.600 | 4.644 | 17.75 | 18.14 |
| Mean | 4.37 | 3.80 | 40.8 | 39.0 | 4.460 | 4.082 | 18.17 | 18.79 |
| s.e.d. | | | | | 0.0940 | | 0.161 | |

Table 4.2.3: Seed dry matter yield, oil content, thousand seed weight and protein content in double-low (DL) winter rape and HEAR at Aberdeen, 1995-6.

| Cultivar | Type | Yield (t/ha @ 90% D.M.) | | Oil content (%) | | Thousand seed weight (g) | | Protein content (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | U | F | U | F | U | F | U |
| Bristol | DL | 4.04 | 2.30 | n.d | n.d | n.d. | n.d. | n.d. | n.d. |
| Corporal | DL | | | 45.0 | 44.9 | 4.187 | 4.038 | 17.30 | 18.42 |
| Ecuador | DL | | | 45.6 | 43.0 | 4.615 | 4.194 | 16.79 | 18.11 |
| Envol | DL | | | 43.0 | 41.5 | 3.972 | 3.763 | 17.25 | 18.94 |
| Express | DL | 5.11 | 4.36 | 46.4 | 44.1 | 3.844 | 3.796 | 16.61 | 17.61 |
| Falcon | DL | 5.16 | 3.92 | 42.1 | 39.8 | 4.104 | 3.810 | 16.74 | 17.92 |
| Gazelle | DL | 5.31 | 3.70 | 39.5 | 39.4 | 3.865 | 3.875 | 17.18 | 18.14 |
| Inca | DL | 5.41 | 3.52 | 43.1 | 42.3 | 4.707 | 4.393 | 15.95 | 17.40 |
| Jazz | DL | 4.97 | 3.45 | 42.9 | 41.1 | 3.927 | 3.921 | 16.90 | 18.49 |
| Lizard | DL | 5.21 | 4.54 | 42.3 | 38.8 | 4.345 | 4.247 | 16.82 | 17.16 |
| Mandarin | DL | | | 39.4 | 36.8 | 3.702 | 3.801 | 17.42 | 19.46 |
| Nickel | DL | 4.97 | 4.17 | 42.6 | 41.8 | 4.548 | 4.319 | 17.20 | 17.63 |
| Rapier | DL | 4.72 | 4.21 | 42.8 | 41.0 | 4.020 | 4.009 | 17.38 | 17.86 |
| Synergy | HVA | 5.45 | 4.10 | 43.7 | 42.0 | 4.180 | 3.740 | 16.28 | 17.27 |
| Askari | HEAR | | | 45.3 | 48.8 | 4.262 | 4.162 | 17.67 | 16.83 |
| Martina | HEAR | | | 46.9 | 48.4 | 4.198 | 4.384 | 18.08 | 18.67 |
| Mean | | | | 43.37 | 42.25 | 4.165 | 4.030 | 17.04 | 18.00 |

Table 4.2.4: Seed dry matter yield, oil content, thousand seed weight and protein content in winter double-low (DL), HEAR and hybrid varietal association (HVA) crops at Brampton in 1995-6.

| Cultivar | Type | Yield (t/ha @ 90% D.M.) | | Oil content (%) | | Thousand seed weight (g) | | Protein content (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | U | F | U | F | U | F | U |
| Bristol | DL | 3.10 | 3.12 | 41.0 | 40.0 | 3.212 | 3.424 | 18.3 | 18.5 |
| Nickel | DL | 3.20 | 3.28 | 43.8 | 42.5 | 3.635 | 3.582 | 17.9 | 18.5 |
| Synergy | HVA | 3.71 | 4.00 | 44.7 | 41.5 | 3.367 | 3.569 | 18.8 | 18.3 |
| Askari | HEAR | | | 42.1 | 42.3 | 3.484 | 3.493 | 19.3 | 20.1 |
| Martina | HEAR | | | 45.2 | 43.9 | 3.659 | 3.370 | 19.5 | 20.3 |
| Mean | | | | 43.4 | 42.0 | 3.471 | 3.487 | 18.8 | 19.1 |

Table 4.2.5: Seed dry matter yield, oil content, thousand seed weight and protein content in winter double-low (DL), HEAR and hybrid varietal association (HVA) crops at Bridgets, 1995-6.

| Cultivar | Type | Yield (t/ha @ 90% D.M.) | | Oil content (%) | | Thousand seed weight (g) | | Protein content (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | U | F | U | F | U | F | U |
| Bristol | DL | 4.93 | 4.16 | 44.5 | 39.2 | 3.597 | 3.280 | 17.5 | 19.0 |
| Express | DL | 4.54 | 4.37 | 45.7 | 44.4 | 3.862 | 3.872 | 18.4 | 17.1 |
| Nickel | DL | 4.93 | 4.37 | 41.9 | 37.8 | 3.522 | 3.500 | 17.2 | 19.3 |
| Synergy | HVA | 5.12 | 4.42 | 40.2 | 37.3 | 4.107 | 3.650 | 18.7 | 19.8 |
| Askari | HEAR | | | 41.7 | 44.9 | 3.696 | 4.042 | 20.5 | 18.6 |
| Martina | HEAR | | | 45.4 | 42.7 | 3.572 | 3.573 | 18.4 | 20.4 |
| Mean | | | | 43.2 | 41.0 | 3.726 | 3.653 | 18.5 | 19.0 |

Table 4.2.6: Seed dry matter yield, oil content, thousand seed weight and protein content in winter double-low (DL), HEAR and hybrid varietal association (HVA) crops at Morley, 1995-6.

| Cultivar | Type | Yield (t/ha @ 90% D.M.) | | Oil content (%) | | Thousand seed weight (g) | | Protein content (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | U | F | U | F | U | F | U |
| Bristol | DL | 4.22 | 4.18 | 42.4 | 38.3 | 3.948 | 4.084 | 18.3 | 18.0 |
| Nickel | DL | 4.14 | 3.90 | 39.7 | 38.3 | 4.197 | 4.183 | 18.7 | 18.4 |
| Synergy | HVA | 4.71 | 3.94 | 39.5 | 40.4 | 4.067 | 4.150 | 19.1 | 19.2 |
| Askari | HEAR | | | 45.7 | 44.4 | 3.703 | 3.747 | 19.4 | 19.1 |
| Martina | HEAR | | | 41.3 | 43.0 | 3.866 | 3.839 | 19.5 | 19.5 |
| Mean | | | | 41.7 | 40.9 | 3.956 | 4.000 | 19.0 | 18.8 |

Table 4.2.7: Seed dry matter yield, oil content and thousand seed weight in double-low (DL) spring rape and HEAR at Aberdeen, 1995-6.

| Cultivar | Type | Oil content (%) | | Thousand seed weight (g) | |
|---|---|---|---|---|---|
| | | F | U | F | U |
| Global | DL | 42.3 | 41.0 | 3.602 | 3.092 |
| Mars | DL | 43.4 | 44.8 | 3.112 | 3.549 |
| Starlight | DL | 43.6 | 42.4 | 3.127 | 3.242 |
| Industry | HEAR | 42.8 | 38.9 | 2.463 | 2.327 |
| Hyola 401 | DL | 40.9 | 40.0 | 3.600 | 3.343 |
| Mean | | 42.6 | 41.4 | 3.180 | 3.111 |

Table 4.2.8: Seed dry matter yield, oil content and thousand seed weight in double-low (DL) spring rape and HEAR at Edinburgh, 1995-6.

| Cultivar | Type | Oil content (%) | | Thousand seed weight (g) | |
|---|---|---|---|---|---|
| | | F | U | F | U |
| Global | DL | 37.7 | 36.1 | 3.978 | 3.860 |
| Mars | DL | 41.9 | 43.5 | 3.912 | 3.835 |
| Starlight | DL | 44.3 | 42.1 | 3.604 | 3.361 |
| Industry | HEAR | 39.1 | 41.3 | 2.998 | 2.968 |
| Hyola 401 | DL | 40.2 | 40.5 | 3.904 | 3.976 |
| Mean | | 40.6 | 40.7 | 3.679 | 3.600 |

4.3: *Oil fatty acid composition, group separations and molecular species pattern.*

The results of the fatty acid profile measurements are summarised in Tables 4.3.1 to 4.3.9.

Severe disease tended to cause changes in the fatty acid composition of the oil. In 1994-5, the greatest changes occurred among winter double-low cultivars that had suffered the greatest reductions in oil content as a result of severe infection, but in 1995-6 this pattern was not repeated. Thus, like oil content, the extent of the changes depended on the type of variety and the local disease pattern. The greatest changes in fatty acid composition among double-lows in 1994-5 were associated with light leaf spot susceptible varieties, where this disease was severe. Oil from more heavily-diseased plots generally contained less oleic acid [18:1] but more polyunsaturated fatty acids (linoleic acid [18:2] and alpha-linolenic acid [18:3]) than that from F plots. No changes in the relative proportions of the saturated fatty acids palmitic acid [16:0] and stearic acid [18:0] were detected. The same overall pattern occurred in 1995-6, but the differences between F and U plots were not as great, possibly because disease incidence tended to be less in that season. Some of the double-low cultivars grown at SAC-Aberdeen and NIAB sites had a greater proportion of [18:1] in the oil from U plots than from sprayed plots in 1995-6. There was little difference in the fatty acid profile in the oils from U and F plots from Brampton, Bridgets and Morley in 1995-6 (Tables 4.3.4 - .6), but incidence of light leaf spot was low at these sites, although some stem canker was recorded.

In 1994-5, the oil from winter HEAR cultivars also had a shift away from [18:1] in I plots, but towards eicosenoic [20:1] and erucic acids [22:1], rather than [18:2] and [18:3]. Winter HEAR cultivars grown in 1995-6 had changes in fatty acid composition between sprayed and unsprayed plots, but without a consistent pattern of change. At Aberdeen, both *Askari* and *Martina* had a greater erucic acid [22:1] content in U plots than F plots, but, at NIAB-Brampton the proportion of erucic acid [22:1] was greater the oil of U plots only for *Askari*, it was less in the oil from U plots of *Martina*. There was similar variation at other sites. Most of the change in the proportion of erucic acid in the oil from U plots of HEARs was accounted for by a commensurate change in the proportion of [18:1]. It was not possible to relate differences in the fatty acid composition in oils from HEAR cultivars in F and U plots with differences in disease patterns across sites.

Oil from spring cultivars grown in 1995-6 also had changes in fatty acid composition as a result of withholding fungicides (Tables 4.3.7 -.8). At Aberdeen, the oil from U plots had consistently smaller proportions of [18:1] than for F plots, whereas at Edinburgh, there was no consistent pattern for the proportion of this fatty acid. The only spring HEAR tested (*Industry*) had no consistent pattern of change in [22:1] at the two sites.

Infection by *Sclerotinia sclerotiorum* appeared to cause different changes in oil content compared to infection by other pathogens. At Rothamsted oil from severely infected plants of the winter double-low cultivar *Apex* differed little from that from uninfected plants in 18-carbon fatty acids, but it contained erucic acid (2.3%) and hexadecatrienoic acid (16:3, 0.7%), which were absent from oil from uninfected plants (Table 4.3.1). Levels of eicosenoic acid (20:1) also increased in the oil of infected plants. The spring cultivar *Hyola 401* grown at SAC-Aberdeen in 1995-6 responded to sclerotinia infection with a similar shift in fatty acids in its oil away from [18:1] towards [18:2] and [18:3], but it did not produce [22:1] in response to infection (Table 4.3.9).

Fungicide treatment generally increased the TAG, but decreased the diacylglycerol (DAG) content of the oil (Tables 4.3.10 & .11). In the two winter cultivars, *Envol* and *Mandarin,* examined in detail, there appeared to be a trend in that U plots produced oil containing greater amounts of TAG molecular species rich in polyunsaturated fatty acids, and lesser amounts of those richer in monounsaturates (Table 4.3.12). The changes in the fatty acid composition of the TAG fraction reflected those in the oil.

Table 4.3.1: Fatty acid composition (% of total) of the oil from the winter HEAR cultivar *Askari* (F-sprayed, U-untreated) and the double-low cultivar *Apex* severely-infected (S) and not infected (N) by stem rot at Rothamsted, 1994-5.

| Cultivar | | 14:0 | 16:0 | 16:3 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Askari | F | - | 4.0 | - | 1.2 | 16.0 | 15.9 | 9.4 | 0.5 | 8.7 | - | 43.5 |
| | U | - | 3.7 | - | 1.2 | 16.0 | 15.3 | 8.9 | 0.5 | 9.2 | - | 44.6 |
| Apex | S | - | 4.6 | 0.7 | 1.0 | 60.4 | 19.4 | 8.3 | - | 0.9 | - | 2.3 |
| | N | - | 5.6 | - | 1.7 | 63.8 | 19.4 | 8.8 | - | 0.8 | - | - |

Table 4.3.2: Fatty acid composition (% of total) of the oil from double-low winter rape at Aberdeen, 1994-5.

| Cultivar | | Fatty acid | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14:0 | 16:0 | 16:3 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| Alaska | F | - | 4.9 | - | 1.1 | 56.1 | 24.0 | 11.3 | - | - | - | - |
| | U | - | 5.1 | - | 1.2 | 54.6 | 22.7 | 12.5 | - | - | - | - |
| Amber | F | - | 4.9 | - | | 59.1 | 22.3 | 11.5 | - | - | - | - |
| | U | - | 4.8 | - | 1.1 | 58.3 | 22.6 | 11.2 | - | - | - | - |
| Apex | F | - | 4.9 | - | 1.5 | 57.0 | 20.8 | 10.7 | - | - | - | - |
| | U | - | 5.3 | - | 1.2 | 54.5 | 23.8 | 11.6 | - | - | - | - |
| Bristol | F | - | 5.2 | - | 1.6 | 54.5 | 23.3 | 10.7 | - | - | - | - |
| | U | - | 5.4 | - | 1.6 | 51.6 | 25.1 | 11.6 | - | - | - | - |
| Cannon | F | - | 5.0 | - | 1.5 | 55.1 | 23.1 | 11.5 | - | - | - | - |
| | U | - | - | - | 1.6 | 54.4 | 23.4 | 11.4 | - | - | - | - |
| Commanche | F | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| | U | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| Envol | F | - | 5.8 | - | | 61.0 | 21.9 | 9.4 | - | - | - | - |
| | U | - | 5.3 | - | 1.4 | 54.7 | 26.1 | 10.8 | - | - | - | - |
| Express | F | - | 5.0 | - | - | 63.5 | 21.2 | 10.2 | - | - | - | - |
| | U | - | 4.7 | - | - | 61.0 | 21.1 | 10.2 | - | - | - | - |
| Falcon | F | - | 5.2 | - | - | 57.5 | 23.8 | 12.2 | - | - | - | - |
| | U | - | 5.7 | - | - | 57.8 | 23.9 | 10.9 | - | - | - | - |
| Gazelle | F | - | 5.8 | - | 1.0 | 52.6 | 25.2 | 11.9 | - | - | - | - |
| | U | 1.8 | 5.7 | - | 1.0 | 52.7 | 25.0 | 12.9 | - | - | - | - |
| Hansen | F | 2.2 | 5.0 | - | 1.6 | 54.2 | 23.2 | 11.2 | - | - | - | - |
| | U | 1.0 | 4.8 | - | 1.5 | 55.6 | 22.8 | 11.0 | - | - | - | - |
| Idol | F | 2.2 | 4.8 | - | 1.4 | 54.2 | 20.9 | 10.7 | - | - | - | - |
| | U | 4.5 | 4.5 | - | 1.5 | 52.6 | 21.5 | 10.3 | - | - | - | - |
| Inca | F | 7.5 | 5.0 | - | 1.5 | 53.3 | 21.0 | 10.3 | - | - | - | - |
| | U | 6.4 | 6.4 | - | 1.3 | 55.7 | 24.3 | 11.5 | - | - | - | - |
| Mandarin | F | - | 6.4 | - | - | 58.1 | 24.5 | 10.9 | - | - | - | - |
| | U | - | 7.0 | - | - | 51.5 | 26.9 | 11.5 | - | - | - | - |
| Nickel | F | - | 5.2 | - | - | 57.8 | 23.9 | 11.6 | - | - | - | - |
| | U | - | 6.4 | - | - | 61.3 | 21.5 | 10.6 | - | - | - | - |
| Rapier | F | - | 5.2 | - | - | 59.2 | 23.1 | 10.6 | - | - | - | - |
| | U | - | 5.1 | - | - | 59.1 | 23.0 | 10.4 | - | - | - | - |
| Rocket | F | - | 5.3 | - | - | 61.4 | 21.7 | 9.7 | - | - | - | - |
| | U | 6.0 | 4.5 | - | - | 56.7 | 21.1 | 9.9 | - | - | - | - |
| Tomahawk | F | 1.5 | 5.3 | - | 1.4 | 54.1 | 22.3 | 10.8 | - | - | - | - |
| | U | - | 5.3 | - | - | 58.8 | 22.3 | 10.4 | - | - | - | - |

Table 4.3.3: Fatty acid composition (% of total) of the oil from winter double-low rape (DL) and HEAR and hybrid varietal association (HVA) crops at Aberdeen, 1995-6.

| Cultivar | Type | | Fatty acid | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| Bristol | DL | F | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| | | U | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| Corporal | DL | F | 7.6 | 2.0 | 56.2 | 19.8 | 10.8 | - | - | - | 3.6 |
| | | U | 5.7 | 1.6 | 54.9 | 25.5 | 12.3 | - | - | - | - |
| Ecuador | DL | F | 5.7 | 1.2 | 60.1 | 20.6 | 12.4 | - | - | - | - |
| | | U | 6.2 | 1.4 | 56.6 | 22.6 | 13.2 | - | - | - | - |
| Envol | DL | F | 5.8 | 1.3 | 60.5 | 20.6 | 11.9 | - | - | - | - |
| | | U | 5.8 | 1.4 | 58.5 | 21.7 | 12.6 | - | - | - | - |
| Express | DL | F | 5.8 | 1.5 | 61.6 | 19.5 | 11.5 | - | - | - | - |
| | | U | 5.7 | - | 62.2 | 20.4 | 11.7 | - | - | - | - |
| Falcon | DL | F | 6.0 | 1.2 | 58.5 | 21.5 | 12.0 | - | - | - | - |
| | | U | 6.0 | 1.4 | 56.6 | 23.0 | 12.6 | - | 0.4 | - | - |
| Gazelle | DL | F | 6.9 | 1.2 | 58.4 | 23.6 | 12.6 | - | - | - | - |
| | | U | 6.8 | - | 55.6 | 24.6 | 13.2 | - | - | - | - |
| Inca | DL | F | 6.4 | 0.7 | 59.7 | 21.1 | 11.3 | - | 0.7 | - | - |
| | | U | 5.7 | 0.9 | 59.2 | 22.5 | 11.7 | - | - | - | - |
| Jazz | DL | F | 5.1 | 1.4 | 57.4 | 22.4 | 12.7 | - | 0.7 | - | - |
| | | U | 6.1 | 1.3 | 55.9 | 22.8 | 12.9 | - | 0.7 | - | - |
| Lizard | DL | F | 6.2 | 1.1 | 58.3 | 20.6 | 13.1 | - | 0.6 | - | - |
| | | U | 6.6 | 1.2 | 57.6 | 20.7 | 13.0 | - | 0.6 | - | - |
| Mandarin | DL | F | 5.7 | 1.9 | 61.0 | 20.4 | 10.5 | - | 0.6 | - | - |
| | | U | 5.2 | 1.4 | 58.3 | 22.0 | 11.9 | 0.5 | 0.8 | - | - |
| Nickel | DL | F | 5.2 | 1.4 | 59.5 | 21.4 | 11.6 | - | 1.0 | - | - |
| | | U | 4.9 | 1.3 | 59.6 | 21.9 | 11.5 | - | 0.9 | - | - |
| Rapier | DL | F | 5.5 | - | 60.4 | 22.0 | 12.1 | - | - | - | - |
| | | U | 5.4 | 1.0 | 58.9 | 22.5 | 12.2 | - | - | - | - |
| Synergy | DL HVA | F | 6.2 | 1.3 | 60.4 | 20.5 | 11.7 | - | - | - | - |
| | | U | 5.7 | 1.3 | 58.1 | 21.6 | 12.3 | 1.0 | - | - | - |
| Askari | HEAR | F | 4.4 | 1.3 | 30.9 | 17.8 | 11.6 | - | 6.0 | - | 27.6 |
| | | U | 9.8 | 4.4 | 22.5 | 14.2 | 9.6 | - | 4.4 | - | 25.2 |
| Martina | HEAR | F | 4.8 | 1.0 | 25.0 | 17.6 | 11.8 | - | 7.2 | - | 32.2 |
| | | U | 3.1 | - | 19.1 | 16.0 | 11.7 | - | 7.7 | - | 42.4 |

Table 4.3.4: Fatty acid composition (% of total) of the oil from winter double-low rape (DL) HEAR and hybrid varietal association (HVA) crops at Brampton, 1995-6.

| Cultivar | Type | | Fatty acid | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| Bristol | DL | F | 5.9 | 1.8 | 56.3 | 21.5 | 11.7 | 0.5 | 1.3 | - | 0.3 |
| | | U | 5.6 | 1.6 | 57.0 | 21.7 | 12.3 | 0.5 | 1.0 | - | 0.4 |
| Nickel | DL | F | 6.6 | 1.5 | 57.6 | 21.4 | 11.3 | - | 1.7 | - | - |
| | | U | 6.2 | 1.7 | 56.5 | 22.3 | 12.6 | - | 0.7 | - | - |
| Synergy | DL HVA | F | 8.0 | 1.2 | 54.6 | 23.2 | 12.7 | - | - | - | - |
| | | U | 7.0 | 0.2 | 56.5 | 22.6 | 12.8 | - | 0.6 | - | - |
| Askari | HEAR | F | 6.2 | 1.3 | 29.4 | 21.4 | 14.1 | - | 3.5 | - | 23.7 |
| | | U | 5.1 | 1.4 | 19.7 | 20.2 | 13.6 | 0.7 | 6.7 | - | 32.2 |
| Martina | HEAR | F | 7.2 | - | 19.3 | 22.0 | 15.7 | - | 5.9 | - | 29.9 |
| | | U | 5.6 | - | 24.7 | 20.3 | 14.1 | - | 7.4 | - | 27.9 |

Table 4.3.5: Fatty acid composition (% of total) of the oil from winter double-low rape (DL) HEAR and hybrid varietal association (HVA) crops at Bridgets, 1995-6.

| Cultivar | Type | | Fatty acid | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| Bristol | DL | F | 5.3 | 1.7 | 58.1 | 21.1 | 11.4 | - | 1.1 | - | 1.3 |
| | | U | 5.2 | 1.5 | 57.1 | 23.5 | 11.3 | 0.4 | 1.0 | - | - |
| Express | DL | F | 5.1 | 1.5 | 60.3 | 20.2 | 11.4 | 0.4 | 1.0 | - | - |
| | | U | 4.7 | 1.7 | 62.6 | 19.1 | 10.5 | 0.5 | 1.0 | - | - |
| Nickel | DL | F | 5.2 | 1.2 | 58.1 | 23.2 | 11.1 | - | - | - | - |
| | | U | 5.1 | 1.3 | 57.5 | 22.7 | 10.3 | 0.4 | 1.4 | - | 1.2 |
| Synergy | DL HVA | F | 5.2 | 1.3 | 53.5 | 22.7 | 12.6 | 0.3 | 2.2 | - | 2.2 |
| | | U | 4.8 | 1.4 | 59.5 | 21.3 | 11.6 | - | 1.2 | - | - |
| Askari | HEAR | F | 4.2 | 1.1 | 10.5 | 19.0 | 12.9 | - | 8.3 | - | 43.0 |
| | | U | 4.0 | 1.2 | 12.9 | 16.8 | 10.2 | 0.7 | 8.6 | - | 44.3 |
| Martina | HEAR | F | 5.7 | 1.0 | 12.9 | 18.2 | 12.7 | - | 9.8 | - | 39.1 |
| | | U | 5.6 | 1.0 | 21.6 | 19.5 | 12.5 | - | 8.1 | - | 31.1 |

Table 4.3.6: Fatty acid composition (% of total) of the oil from winter double-low rape (DL) HEAR and hybrid varietal association (HVA) crops at Morley, 1995-6.

| Cultivar | Type | | Fatty acid | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| Bristol | DL | F | 5.0 | 1.5 | 60.7 | 20.6 | 11.1 | - | 1.0 | - | - |
| | | U | 4.7 | 1.5 | 60.4 | 20.7 | 11.0 | - | 1.2 | - | 0.6 |
| Nickel | DL | F | 4.5 | 1.3 | 59.4 | 22.2 | 11.5 | - | 1.1 | - | - |
| | | U | 4.5 | 1.4 | 59.1 | 22.3 | 11.2 | 0.5 | 1.1 | - | - |
| Synergy | DL HVA | F | 4.9 | 1.3 | 56.0 | 22.5 | 12.5 | 0.5 | 1.4 | - | - |
| | | U | 5.1 | 0.2 | 55.3 | 22.3 | 13.4 | 0.4 | 1.5 | - | - |
| Askari | HEAR | F | 3.9 | 1.1 | 13.1 | 16.5 | 10.5 | - | 7.4 | - | 47.0 |
| | | U | 3.7 | - | 13.4 | 17.1 | 10.7 | - | 7.8 | - | 47.3 |
| Martina | HEAR | F | 4.1 | 1.0 | 13.1 | 15.6 | 11.1 | - | 8.8 | - | 46.3 |
| | | U | 4.8 | 1.0 | 16.4 | 17.6 | 12.2 | - | 8.6 | 0.6 | 38.2 |

Table 4.3.7: Fatty acid composition (% of total) of the oil from spring double-low rape (DL) and HEAR plots at Aberdeen, 1995-6.

| Cultivar | Type | | Fatty acid | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| Global | DL | F | 5.3 | - | 60.8 | 23.3 | 10.7 | - | - | - | - |
| | | U | 4.9 | 1.5 | 57.4 | 24.4 | 10.7 | - | 1.1 | - | - |
| Mars | DL | F | 5.1 | - | 60.6 | 22.6 | 11.7 | - | - | - | - |
| | | U | 6.2 | - | 57.5 | 24.2 | 12.2 | - | - | - | - |
| Starlight | DL | F | 6.2 | - | 60.8 | 22.4 | 10.6 | - | - | - | - |
| | | U | 5.6 | - | 58.3 | 22.4 | 11.1 | - | 2.6 | - | - |
| Industry | HEAR | F | 8.3 | - | 20.7 | 22.9 | 15.5 | - | 3.1 | - | 29.5 |
| | | U | 8.2 | - | 19.2 | 23.6 | 15.3 | - | 3.4 | - | 30.4 |
| Hyola | DL | F | 5.0 | 1.6 | 62.1 | 20.6 | 10.7 | - | - | - | - |
| | | U | 4.9 | 1.9 | 61.2 | 20.5 | 10.5 | - | 1.0 | - | - |

Table 4.3.8: Fatty acid composition (% of total) of the oil from spring double-low rape (DL) and HEAR at Edinburgh, 1995-6.

| Cultivar | Type | | Fatty acid | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| Global | DL | F | 5.9 | - | 59.9 | 22.7 | 11.6 | - | - | - | - |
| | | U | 4.5 | - | 61.1 | 22.5 | 11.9 | - | - | - | - |
| Mars | DL | F | 4.5 | - | 62.9 | 20.8 | 11.8 | - | - | - | - |
| | | U | 4.3 | - | 62.9 | 20.8 | 11.8 | - | - | - | - |
| Starlight | DL | F | 4.6 | - | 63.0 | 20.9 | 11.5 | - | - | - | - |
| | | U | 4.9 | - | 62.8 | 20.7 | 11.6 | - | - | - | - |
| Industry | HEAR | F | 4.0 | - | 47.6 | 19.5 | 12.3 | - | 1.6 | - | 15.0 |
| | | U | 4.3 | 1.5 | 48.4 | 19.8 | 11.9 | - | 1.0 | - | 13.3 |
| Hyola 401 | DL | F | 5.2 | - | 64.0 | 18.2 | 12.6 | - | - | - | - |
| | | U | 6.5 | - | 60.9 | 19.8 | 12.8 | - | - | - | - |

Table 4.3.9: Fatty acid composition (% of total) of the oil from plants selected from spring rape (*Hyola 410*) plots as either severely-infected (S) or not infected (N) by sclerotinia stem rot at Aberdeen, 1995-6.

| | Fatty acid | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 20:2 | 22:1 |
| S | 4.9 | 1.8 | 61.7 | 19.4 | 10.9 | 0.5 | 0.8 | - | - |
| N | 5.2 | 2.1 | 63.4 | 18.1 | 10.6 | - | 0.7 | - | - |

Table 4.3.10: Group separations of the oil from selected winter double-low rape (DL) and HEAR cultivars at Aberdeen, 1995-6.

| Cultivar | Type | | | | | Fatty acid composition (TAG only) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MAG | DAG | TAG | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 22:1 |
| Ecuador | DL | F | 0.2 | 2.0 | 97.1 | 5.7 | 1.2 | 58.2 | 22.0 | 12.0 | - | 0.6 | - |
| | | U | 0.2 | 2.5 | 96.2 | 5.6 | 1.1 | 57.8 | 22.5 | 12.2 | - | 0.8 | - |
| Express | DL | F | 0.2 | 4.4 | 93.4 | 5.3 | 1.5 | 63.0 | 19.1 | 10.0 | - | 0.8 | - |
| | | U | 0.1 | 4.4 | 94.4 | 5.3 | 1.5 | 60.7 | 20.6 | 11.0 | - | 0.9 | - |
| Falcon | DL | F | 0.4 | 3.1 | 95.7 | 5.9 | 1.3 | 59.2 | 21.6 | 11.2 | - | 0.8 | - |
| | | U | 0.2 | 3.8 | 94.5 | 5.8 | 1.4 | 56.5 | 23.0 | 11.8 | 0.4 | 0.9 | - |
| Lizard | DL | F | 0.2 | 3.2 | 96.1 | 5.4 | 1.2 | 59.0 | 20.4 | 12.1 | - | 1.2 | 0.6 |
| | | U | 0.3 | 11.0 | 87.9 | 5.6 | 1.3 | 57.8 | 21.1 | 12.7 | 0.4 | 0.9 | - |
| Mandarin | DL | F | 0.2 | 1.2 | 98.0 | 5.4 | 1.3 | 59.9 | 21.7 | 10.9 | - | 0.7 | - |
| | | U | 0.2 | 2.4 | 96.5 | 5.3 | 1.5 | 58.8 | 21.9 | 11.2 | - | 1.0 | - |
| Martina | HEAR | F | 0.1 | 3.4 | 95.9 | 4.9 | 1.4 | 25.0 | 17.0 | 11.4 | - | 7.8 | 32.5 |
| | | U | 0.3 | 4.4 | 94.7 | 4.8 | 1.1 | 23.1 | 17.5 | 12.5 | - | 7.4 | 33.4 |

Table 4.3.11: Group separations of the oil from selected winter double-low rape (DL), HEAR and hybrid varietal association (HVA) crops at Bridgets, 1995-6.

| Cultivar | Type | | | | | Fatty acid composition (TAG only) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MAG | DAG | TAG | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 22:1 |
| Bristol | DL | F | 0.0 | 1.4 | 98.3 | 5.6 | 1.6 | 58.9 | 21.6 | 11.1 | - | 0.9 | - |
| | | U | 0.0 | 1.3 | 98.2 | 6.0 | 1.6 | 57.4 | 23.4 | 10.4 | - | 1.0 | - |
| Express | DL | F | 0.2 | 1.6 | 98.0 | 5.3 | 1.5 | 60.2 | 20.6 | 11.2 | - | 0.9 | - |
| | | U | 0.0 | 1.6 | 97.7 | 5.7 | 1.6 | 59.3 | 21.4 | 11.8 | - | - | - |
| Nickel | DL | F | 0.0 | 1.0 | 98.9 | 5.4 | 1.5 | 60.3 | 22.3 | 9.6 | - | 0.8 | - |
| | | U | 0.0 | 1.2 | 98.6 | 5.1 | 1.2 | 58.4 | 24.0 | 10.2 | - | 0.9 | - |
| Synergy | DL HVA | F | 0.5 | 1.4 | 98.1 | 5.9 | 1.4 | 55.8 | 23.3 | 12.4 | - | 1.3 | - |
| | | U | 0.0 | 0.9 | 98.8 | 5.4 | 1.5 | 59.7 | 21.5 | 10.6 | - | 1.0 | - |
| Martina | HEAR | F | 0.0 | 1.8 | 98.1 | 8.1 | 2.4 | 20.4 | 28.2 | 19.9 | 1.3 | 18.4 | 0.8 |
| | | U | 0.0 | 1.9 | 97.9 | 7.9 | 1.8 | 32.2 | 27.1 | 16.5 | - | 13.7 | 0.8 |

Table 4.3.12: TAG molecular species in the oil from selected winter double-low (DL) rape cultivars at Aberdeen, 1994-5.

| *Envol* (DL) | | | | | *Mandarin* (DL) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Band no. | Molecular composition * | Degree of unsatur-ation | Approx. content (%) | | Band no. | Molecular composition* | Degree of unsatur-ation | Approx. content (%) | |
| | | | F | U | | | | F | U |
| 0 | MDT | 6 | 3.0 | 3.5 | 0 | MDT | 6 | 3.8 | 5.1 |
| 1 | DDT,MTT | 7 | 5.3 | 6.3 | 1 | MDT | 6 | 14.4 | 15.1 |
| 2 | MDT | 6 | 10.6 | 8.9 | 2 | MDD,MMT | 5 | 15.0 | 13.2 |
| 3 | MMT,DDM | 5 | 10.7 | 11.6 | 3 | MDD,MMT | 5 | 13.3 | 14.8 |
| 4 | DDM,MMT | 5 | 12.8 | 14.4 | 4 | MMD | 4 | 20.8 | 21.3 |
| 5 | MMD | 4 | 23.8 | 22.1 | 5 | SMD,$M_3$ | 3 | 20.5 | 19.6 |
| 6 | $M_3$ | 3 | 22.3 | 22.9 | 6 | $M_3$,DSS | 3 | 9.3 | 9.2 |
| 7 | SMM | 2 | 11.6 | 10.4 | 7 | SMM | 2 | 2.9 | 1.8 |

* Where two molecular species are presented, the first represents the major component.

Table 4.4.1: Seed chlorophyll content and acid value from winter double-low rape at Rothamsted, 1994-5.

| Cultivar | Chlorophyll content (mg/kg) | | Dry matter acid value | |
|---|---|---|---|---|
| | F | I | F | I |
| Capricorn | 1.13 | 1.75 | 1.145 | 1.235 |
| Falcon | 0.53 | 0.15 | 0.432 | 0.608 |
| s.e.d. | 0.250 | | 0.3224 | |
| Mean | 0.83 | 0.95 | 0.788 | 0.921 |
| s.e.d. | 0.109 | | 0.2915 | |

4.4: *Levels of contaminants in the oil.*

There were no consistent patterns of differences in concentrations of seed chlorophylls between fungicide treated and untreated plots (Tables 4.4.1-4.4.7). For example, at Rothamsted in 1994-5, chlorophyll content of seed was higher in inoculated plots of cultivar *Capricorn* but lower in plots of *Falcon*. At Aberdeen in 1994-5 seed from untreated plots tended to have slightly lower chlorophyll content than sprayed plots but in 1995-6 the trend was reversed (Tables 4.4.2 & .3). Similarly at Brampton, Bridgets and Morely in 1995-6 no consistent patterns of differences

between sprayed and unsprayed plots were found for either double -low or HEAR cultivars: at Bridgets concentrations were marginally higher in untreated plots but at the other two sites they tended to be similar for both sprayed and unsprayed plots (Tables 4.4.4-.6). The chlorophyll content of seed from the spring rape trials at Aberdeen and Edinburgh generally differed little between F and U treatments (Table 4.4.7). The results suggest that chlorophyll concentration in seed is not significantly affected by disease.

Table 4.4.2: Seed chlorophyll concentration, acid value and peroxide value in the oil from winter double-low rape at Aberdeen, 1994-5.

| Cultivar | Type | Chlorophyll content (mg/kg) | | Acid value | | Peroxide value | |
|---|---|---|---|---|---|---|---|
| | | F | U | F | U | F | U |
| Alaska | DL | 19.93 | 16.20 | 0.53 | 0.65 | 28.05 | 20.52 |
| Amber | DL | 34.21 | 27.71 | 0.34 | 0.36 | 5.37 | 5.52 |
| Apex | DL | 75.14 | 35.59 | 0.32 | 0.40 | 10.49 | 12.33 |
| Bristol | DL | 19.14 | 15.77 | 0.58 | 0.45 | 5.60 | 7.65 |
| Cannon | DL | 46.13 | 30.30 | 0.71 | 0.76 | 4.12 | 7.69 |
| Commanche | DL | 28.23 | 22.63 | 0.45 | 0.57 | 3.77 | 4.70 |
| Envol | DL | 20.25 | 18.80 | 0.45 | 0.63 | 5.35 | 5.95 |
| Express | DL | 27.09 | 16.52 | 0.30 | 0.47 | 4.82 | 3.65 |
| Falcon | DL | 21.21 | 20.91 | 0.51 | 0.54 | 6.51 | 8.36 |
| Gazelle | DL | 26.07 | 19.15 | 0.53 | 0.84 | n.d. | n.d. |
| Hansen | DL | 21.98 | 18.33 | 0.67 | 0.59 | 9.05 | 8.51 |
| Idol | DL | 17.55 | 19.59 | 0.47 | 0.55 | 8.26 | 8.81 |
| Inca | DL | 33.69 | 29.87 | 0.47 | 0.54 | 12.40 | 9.73 |
| Mandarin | DL | 29.00 | 18.62 | 0.65 | 0.74 | 8.21 | 17.40 |
| Nickel | DL | 20.26 | 18.53 | 0.36 | 0.34 | 7.07 | 5.42 |
| Rapier | DL | 20.99 | 16.34 | 0.34 | 0.35 | n.d. | n.d. |
| Rocket | DL | 19.12 | 18.31 | 0.30 | 0.46 | n.d. | n.d. |
| Tomahawk | DL | 20.92 | 22.33 | 0.37 | 0.38 | n.d. | n.d. |
| Mean | | 27.83 | 21.42 | 0.46 | 0.53 | 8.51 | 9.02 |
| s.e.d. | | | | 0.024 | | 0.863 | |

The effect of fungicide treatment on acid value was also variable (Tables 4.4.1-.6). For example, it was higher in untreated plots in some experiments in 1994-5, but unaffected in others. Overall, acid values were generally low for all crude oils and clearly the free fatty acid content is unaffected by disease.

Peroxide values were only determined for trial at Aberdeen in 1994-5. There was no consistent effect of fungicide treatment on the peroxide value of the oil in these trials (Table 4.4.2).

Table 4.4.3: Seed chlorophyll concentration from rape at Aberdeen, 1995-6.

| Cultivar | Type | Chlorophyll content (mg/kg) | |
|---|---|---|---|
| | | F | U |
| Bristol | DL | n.d. | n.d. |
| Corporal | DL | 19.53 | 17.62 |
| Ecuador | DL | 13.19 | 14.64 |
| Envol | DL | 15.29 | 18.39 |
| Express | DL | 15.92 | 16.41 |
| Falcon | DL | 12.09 | 16.98 |
| Gazelle | DL | 13.96 | 14.76 |
| Inca | DL | 9.33 | 14.53 |
| Jazz | DL | 15.59 | 14.03 |
| Lizard | DL | 15.59 | 10.24 |
| Mandarin | DL | 11.24 | 14.10 |
| Nickel | DL | 9.92 | 12.89 |
| Rapier | DL | 10.88 | 12.62 |
| Synergy | HVA | 11.87 | 10.46 |
| Askari | HEAR | 14.84 | 12.59 |
| Martina | HEAR | 8.77 | 14.70 |
| Mean | | 13.2 | 14.3 |

Table 4.4.4: Seed chlorophyll concentration, acid value in the oil from rape at Bridgets, 1995-6.

| Cultivar | Type | Chlorophyll content (mg/kg) | | Acid value | |
|---|---|---|---|---|---|
| | | F | U | F | U |
| Bristol | DL | 16.0 | 19.6 | 0.61 | 0.61 |
| Express | DL | 17.8 | 17.8 | 0.46 | 0.40 |
| Nickel | DL | 12.7 | 15.2 | 0.43 | 0.75 |
| Synergy | HVA | 12.4 | 19.1 | 0.47 | 0.68 |
| Askari | HEAR | 21.5 | 23.8 | 0.47 | 0.68 |
| Martina | HEAR | 13.0 | 28.3 | 0.51 | 0.69 |
| Mean | | 15.6 | 20.6 | 0.49 | 0.64 |

Table 4.4.5: Seed chlorophyll concentration, acid value in the oil from rape at Brampton, 1995-6.

| Cultivar | Type | Chlorophyll content (mg/kg) | | Acid value | |
|---|---|---|---|---|---|
| | | F | U | F | U |
| Bristol | DL | 16.9 | 15.5 | 0.75 | 0.77 |
| Nickel | DL | 21.6 | 21.6 | 0.67 | 0.49 |
| Synergy | HVA | 17.4 | 15.7 | 0.83 | 0.75 |
| Askari | HEAR | 13.5 | 13.3 | 0.43 | 0.41 |
| Martina | HEAR | 21.4 | 22.9 | 0.86 | 0.66 |
| Mean | | 18.2 | 17.8 | 0.71 | 0.62 |

Table 4.4.6: Seed chlorophyll concentration, acid value in the oil from rape at Morley, 1995-6.

| Cultivar | Type | Chlorophyll content (mg/kg) | | Acid value | |
|---|---|---|---|---|---|
| | | F | U | F | U |
| Bristol | DL | 22.9 | 25.0 | 0.49 | 0.92 |
| Nickel | DL | 20.3 | 16.1 | 0.64 | 0.74 |
| Synergy | HVA | 20.7 | 24.3 | 0.75 | 0.77 |
| Askari | HEAR | 23.1 | 23.9 | 0.68 | 0.68 |
| Martina | HEAR | 18.2 | 24.6 | 0.82 | 0.91 |
| Mean | | 21.0 | 22.8 | 0.68 | 0.80 |

Table 4.4.7: Seed chlorophyll concentration (mg $kg^{-1}$) in spring rapes, 1995-6.

| Cultivar | Aberdeen | | Edinburgh | |
|---|---|---|---|---|
| | F | U | F | U |
| Global | 19.08 | 26.55 | 14.21 | 12.61 |
| Mars | 32.03 | 32.54* | 17.40 | 17.29 |
| Starlight | 32.54 | 31.24 | 15.26 | 12.62* |
| Industry | 44.19 | 36.29* | 15.83 | 16.73 |
| Hyola 401 | 19.70 | 24.10 | 16.96 | 15.68 |

# 5: DISCUSSION

This study has shown not only that fungal infection of oilseed rape can result in significant losses in seed dry matter and oil content, but also that it can affect other important parameters of seed quality that are significant both to processors and to end-users.

## 5.1: *Oil content.*

The most important effect of disease was that on seed yield and oil content. Infection generally reduced oil content in susceptible double-low, although not in HEAR cultivars. In the double-low cultivars, particularly the susceptible types, disease resulted in a decrease in oil content which was accompanied by a reduction in seed size. These seeds were frequently shrivelled, which may have increased the relative proportions of the seed coat component, so reducing the oil content, as a physical consequence. The nature and importance of this relationship is unclear. This relationship, however, holds irrespective of the type of the disease (Arnholdt and Marquard, 1978). Differences in oil content between graded seed samples of the same diameter from fungicide-treated and inoculated plots of the 1994-5 double-low and HEAR cultivars at IACR-Rothamsted suggest that disease also affects oil content directly.

Oil yields in the inoculated and untreated plots, especially with susceptible types, were frequently considerably lower than those of the sprayed plots. In combination with the reduction in dry matter yield, the lower oil content led to decreased oil yields at many sites. For example, inoculated plots of the light leaf spot susceptible cultivar *Capricorn* gave 460 kg $ha^{-1}$ (31%) less oil than fungicide-treated plots in 1994-5 at IACR-Rothamsted. Losses in oil content in unprotected plots have been reported by others (Rawlinson *et al.*, 1989; Sweet *et al.*, 1989), although the effects appear to be seasonal: other reports document the failure of fungicide applications to increase oil content (Church and Fitt, 1995), or the failure of infection to decrease it (Degenhardt *et al.*, 1974).

Although all plots (including those treated with fungicides) contained plants infected by several diseases at various times of the season, differences between treatments could sometimes be attributed to particular diseases. The strong correlation between light leaf spot incidence in April and final oil content in the winter rape experiment at SAC-Aberdeen in 1994-5 suggests that in that season at least, this disease was a major factor determining yield and quality. The strength of this association, irrespective of whether or not fungicides were applied, is surprising, because environmental factors are known to have strong effects on various parameters of seed quality (DeClerq *et al.*, 1995; Ward *et al.*, 1995). It also implies that, in these experiments, differences between fungicide-treated and -untreated plots were not only attributable to the fungicide itself, but that disease had a direct effect on oil content and fatty acid composition. In other experiments, azole compounds such as those used in these experiments have been shown to combine fungicidal action with direct effects on the physiology of rape (Stafford *et al.*, 1995).

## 5.2: *Protein content.*

The increase in protein content in heavily-infected double-low samples from SAC may be partly attributable to the effect of disease on oil content, because protein content is known to be generally inversely related to oil content (Uppström, 1995). However, Kübler and Aufhammer (1990) found that a fungicidal triazole plant growth regulator controlled Phoma and increased protein content without affecting oil content. The effect of disease on protein content may be associated with a change in the carbon-nitrogen balance in severely-infected plants. Low photosynthesis might result in low C:N ratios, favouring the production of protein, rather than oil.

## 5.3: *Fatty acid composition.*

Infection can change the fatty acid composition of the oil. The two diseases studied in most detail, light leaf spot and stem rot, appeared to have broadly similar effects. The most consistent

changes in fatty acid composition occurred where disease was severe. Although the situation was complex, there were trends according to cultivar type: double-low types usually showed increases in linoleic acid [18:2] and α-linolenic acid [α-18:3] at the expense of oleic acid [18:1] in untreated plots, whereas HEAR types sometimes showed an increase in erucic acid [22:1] at the expense of the 18-carbon fatty acids.

While disease did elicit a change in the fatty acid composition of the oil with a lowering of the monounsaturated [18:1]- and an increase in the polyunsaturated [18:2 & 18:3]- fatty acids, this may be beneficial in terms of nutritional quality since the last two are essential fatty acids. Such changes in composition would have marginal effects on the stability of the refined oil and its usefulness in food applications, for example, in frying quality. In extreme cases, the reduction in 18:1 could reduce the quality of certain oils for industrial uses, such as lubricants (Carruthers *et al.*, 1995).

the occasional increase in erucic acid in unprotected plots of HEAR cultivars does not represent a loss in quality. However, the importance of the increase in this acid in a sclerotinia-infected winter double-low crops depends on the reliability of inferring, from experiments on rats, the possibility that it can cause damage to human tissues (Ackman, 1990, Niewiadomski, 1990). Nevertheless, there are official directives that specify maximum levels of this fatty acid in oil intended for human consumption, which could possibly be compromised in severely infected crops. For industrial use, an increase in erucic acid in untreated plots would represent an ostensible improvement in the quality of HEAR oil (although this will be offset by the loss in seed dry matter yield that inevitably results from severe disease). Thus the importance of the loss in the quality of the oil from crops grown without fungicides will depend critically on the type of cultivar, and the end-use intended for the oil.

Below a threshold of severity, the effects of disease are probably secondary to those of other environmental or site-related factors that also affect composition. The changes that severe disease caused in the relative amounts of the main fatty acids characteristic of a particular cultivar were relatively small, compared with those known to be brought about by other, environmental factors. For example, Wilmer *et al.* (1996) report that the erucic acid content of oil from an HEAR cultivar dropped by 30% when it was grown at 15$^0$C rather than 25$^0$C. However, the combination of relatively small fluctuations in oil composition and larger reductions in oil yield as the result of severe infection in our study may represent significant and valuable losses of the desired end-product.

The pattern of changes in fatty acid composition in heavily-diseased plots suggests that infection causes a general increase in unsaturated, longer-chain fatty acids, although the different changes in the fatty acid composition of oil from cultivar *Apex* under conditions of severe light leaf spot (at SAC-Aberdeen in 1994-5) and severe sclerotinia (at IACR-Rothamsted in 1994-5) implies that the effects of disease on seed quality cannot be generalised. These specific effects on oil composition were strongly associated with changes in oil content: among the cultivars used in the SAC-experiment, those most susceptible to light leaf spot showed the biggest changes in both oil content and fatty acid composition. The appearance of erucic acid in sclerotinia-infected plants of cultivar *Apex* at Rothamsted (Table 4.3.1) is surprising. The possibility of contamination by HEAR pollen can be discounted, because the nearest HEAR crop was more than 1km away, and there was no difference in flowering time between plants that eventually became severely infected with sclerotinia and those that did not. Because oil composition usually remains constant from shortly after the time of the onset of oil deposition in developing seeds, disease may have affected fatty acid composition indirectly, possibly through impairment of photosynthetic capacity.

5.4: *Contaminants.*

Finally, losses in oil quality in crops grown without fungicides may be exacerbated further by changes in the levels of certain contaminants in the oil that have to be removed during processing.

Chlorophyll content was generally high in all plots of the 1994-5 experiment, reaching levels that would be unacceptable to processors. But the higher chlorophyll content of oil from fungicide-treated plots is surprising, because it suggests that heavily-infected plots were more mature at harvest. This contradicts the trend in the HEAR experiment at IACR-Rothamsted, in which chlorophyll was slightly lower overall in fungicide-treated plots, and also previous work at Rothamsted (Doughty *et al.*, 1995) and in Canada (Seidle *et al.*, 1995), in which green seed counts were increased by severe infection of oilseed rape and canola (*Brassica rapa*) by light leaf spot, and alternaria blackspot, respectively. It is difficult to determine whether disease increases chlorophyll content significantly. In practice, light leaf spot on pods causes patchy maturation, and may therefore induce farmers to harvest unprotected crops prematurely, hence the perception that the disease increases chlorophyll content.

Severe light leaf spot elevated the levels of free fatty acids, which are undesirable, but these changes were small and would not seriously affect the quality of the oil. This contradicts the work of May *et al.* (1994) who reported that benomyl applications had no effect on free fatty acid content in spring canola seed in Canada (although other forms of stress, such as drought, did increase it) and Kübler & Aufhammer (1990), who showed that a fungicidal triazole growth regulator had no consistent effect on the seed quality of winter oilseed rape.

5.5: *Implications.*

The incorporation of genetic resistance into both food-use and industrial rape varieties would appear to be essential to maintaining the quality of the oil they produce. Otherwise, these crops are likely to depend on the directed, economic use of fungicides if customers are to be supplied consistently with oil of the appropriate quality.

The results of these experiments imply that there is a danger that the yield of desired products will be lower, and the incidence of contaminants that hinder processing higher, if fungicides are withheld from oilseed rape. Growing industrial oils from rape varieties under low-input systems would be attractive, both environmentally and economically. New, specialist-oil varieties will be required to produce specific fatty acids more cheaply than a range of alternative, more traditional crops or mineral oil sources, if they are to be competitive. However, specialist-oil cultivars may be particularly vulnerable to the effects of disease, because their success will be most dependent on guaranteeing a supply of a particular fatty acid, although the differential changes in concentrations of particular fatty acids under conditions of severe infection suggest that some of these cultivars will be more vulnerable than others. However, improvements in oil yield and quality following fungicide treatment need to be offset against the economic and environmental costs of fungicide application, and fungicides must be targeted according to the perceived risk of severe epidemics of particular diseases. Mid-flowering sprays to control Sclerotinia when previous cropping and prevailing weather conditions predispose the crop to severe infection may prevent the appearance of harmful fatty acids in the oil. The experiments at SAC-Aberdeen have also underlined the value of applying fungicides to control light leaf and pod spot, under Scottish conditions, when susceptible cultivars are grown. Resistant cultivars were much less responsive to fungicides in terms of seed quality. Industrial crops on set-aside should use light leaf spot-resistant cultivars in order to guarantee maximum oil yield and quality under low-input conditions. Disease resistance should also be a high priority for breeders of new, specialist-oil cultivars.

There is clear evidence from this study that in the absence or low incidence of disease or with non-susceptible varieties, the application of fungicide increased both the yield of seed, seed size and the oil content. This fungicide growth promoter effect could be responsible for the effects observed with most crops, with the exception those at Aberdeen involving the varieties susceptible to and affected by a high incidence of light leaf spot. In these instances, the disease was responsible for the considerable differences observed in all the quality and yield parameters examined. Such effects must be considered separately from the other observations involving disease resistant types and low incidence of disease, if the specific effects of disease on seed and oil yield and quality are to be defined.

Over a number of years the phytotonic effect of triazole and imidazole fungicides has been recognised but the quantification of this effect has been very difficult to assess because of the experimental design and the failure to assess the level and incidence of disease. The observations obtained in this study could provide the most reliable information on this effect since in all cases the incidence and severity of the diseases was assessed. This aspect was only identified during the preparation of this report. To analyse the data fully with respect to this phytotonic effect will take considerable time and rather than delay the submission of this report, it will be undertaken later. This observation does in no way detract from the significance of the major disease effects.

## 6: CONCLUSIONS

- Fungal disease affects the yield and quality of the oil from rape seed. It can also change the levels of certain contaminants in the oil. The importance of the changes depends on the use intended for the oil: they are not exclusively deleterious.
- The changes that diseases cause differ between pathogens. Oil content and quality is particularly vulnerable if there is a risk of severe light leaf spot.
- Different types of rape cultivar suffer different changes in oil quality in unprotected plots.
- By suppressing diseases with fungicides, growers can maintain the quality of the seed they produce, and they may be less likely to have seed rejected or downgraded by processors because of the presence of contaminants in the oil. However, the requirement for fungicides will depend on which diseases are prevalent, and on which type of crop is being grown.
- Crops (other than high erucic acid rapes) grown for future 'industrial' uses, from which high yields of specific, valuable fatty acids are required, are likely to depend on protection with fungicides: this may determine their economic viability.
- Fungicide applications may improve both the yield and oil content of oilseed rape through effects [phytotonic] that are unrelated to any fungicidal properties.

## 7: ACKNOWLEDGEMENTS

We are grateful to Said Ibrahim and Jill Hopkinson for help with sample preparation, and to Claire Lewis and Suzanne Jobes for help with sample analysis. We thank Alan Todd (Statistics Dept, IACR-Rothamsted) and Andy Sheridan (SAC Aberdeen) for providing agronomic information. for advice on statistical analysis of data. We are also grateful to John K King & Sons Ltd, Zeneca etc. for supplying seeds for the experiments.

8: REFERENCES

ACKMAN, R.G. (1990). Canola fatty acids - an ideal mixture for health, nutrition and food use. Pp 81-98 in *Canola and Rapeseed: Production, Chemistry, Nutrition and Processing Technology* (Ed. F.Shahidi). Van Nostrand Reinhold, New York.

ARNHOLDT, B. and MARQUARD, R. (1978). Protein und Fettgehalt sowie Aminosäure und Fettsäure-muster verschiedener Rapsinzuchtlinien unter Berücksichtigung von Korngrösse und spezifischem Gewicht. *Proceedings of the GCIRC Fifth International Rapeseed Congress, Malmö, Sweden* **2**, 31.

ASKEW, M.F. (1995). Weed control in industrial crops. *Brighton Crop Protection Conference - Weeds* **3**, 1181-1192

BOCK, C.H., DOUGHTY, K.J., FIELDSEND, J.K., SPINK, J, BILSBORROW, P.E., RAWLINSON, C.J. and MILFORD, G.F.J. (1991). Effects of fungicides and disease on growth parameters and seed glucosinolate concentration of oilseed rape. *Proceedings of the GCIRC Eighth International Rapeseed Congress, Saskatoon, Canada,* **6**, 1737-1742.

BOWERMAN, P., YOUNG, J.E.B., COOK, S.K., JONES, A.E. and GREEN, M. (1994). Economic results of farming with reduced levels of inputs: report of the first years of TALISMAN. *Arable farming under CAP reform, Aspects of Applied Biology* **40**, 69-76.

CARRUTHERS, S.P., MARSH, J.S., TURNER, P.W., ELLIS, F.B., MURPHY, D.J., SLABAS, T, and CHAPMAN, B.A. (1995). Industrial markets for UK-produced oilseeds. *HGCA Research Review* **OS9**. Home-grown Cereals Authority, London..

CHURCH, V.J. and FITT, B.D.L. (1995). Incidence and effects of disease on seven winter oilseed rape cultivars in 1991/2 and 1992/3. I*OBC/WPRS Bulletin* **18**, 62-68.

DAUN, J.K. (1995). Seed analysis. Pp. 243-265 in *Brassica Oilseeds: Production and Utilization* (Eds D.S.Kimber and D.I.McGregor), CAB International/Cambridge University Press, Cambridge.

DECLERQ, D.R., DAUN, J.K. and TIPPLES, K.H. (1995). *Quality of Western Canadian Canola. Crop Bulletin* **224**, Agriculture Canada.

DEGENHARDT, K.J., SKOROPAD, W.P. and KONDRA, Z.P. (1974). Effect of Alternaria blackspot on yield, oil content and protein content of rapeseed. *Canadian Journal of Plant Science* **54**, 795-799.

DOUGHTY, K.J., PETINON, S. and McCARTNEY, H.A. (1995). A comparison of the effects of fungal disease on the growth and yield of two winter oilseed rape (*Brassica napus* L.) cultivars. *Physiological Responses of Plants to Pathogens, Aspects of Applied Biology* **42**, 43-51.

JORDAN, V.W.L. and HUTCHEON, J.A. (1994). Economic viability of less-intensive farming systems designed to meet current and future policy requirements: 5-year summary of the LIFE project. *Arable farming under CAP reform, Aspects of Applied Biology* **40**, 61-68

KÜBLER, E. and AUFHAMMER, W. (1990). Einflüsse von Triazolapplikationen auf Kornertrag und -qualität von Winterraps. *Fat Science and Technology* **92**, 68-74.

McDONALD, B.E, GERRARD, J.M., BRUCE, V.M. and CORNER, E.J. (1989). Comparison of the effect of canola oil and sunflower oil on plasma lipids and lippoproteins and on *in vivo*

thromboxane A2 and prostacyclin production in healthy young men. *American Journal of Clinical Nutrition.* **50**, 1383.

MAY, W.E., HUME, D.J. and HALE, B.A. (1994). Effect of agronomic practices on free fatty acid levels in the oil of Ontario-grown spring canola. *Canadian Journal of Plant Science* **74**, 267 - 274.

NIEWIADOMSKI, H. (1990). *Rapeseed Chemistry and Technology.* Developments in Food Science 23. Elsevier/Polish Scientific Publishers.

RAWLINSON, C.J., DOUGHTY, K.J., BOCK, C.H., CHURCH, V.J., MILFORD, G.F.J. and FIELDSEND, J.K. (1989). Diseases and responses to disease and pest control in single- and double-low cultivars of winter oilseed rape. *Aspects of Applied Biology* **23**, 393-400.

SEIDLE, E., RUDE, S. and PETRIE, A. (1995). *The effect of Alternaria blackspot of canola on seed quality and seed yield, and studies on disease control.* Agriculture and Agri-Food Canada, Saskatoon.

SONNTAG, N.O.V. (1995). Industrial utilization of long-chain fatty acids and their derivatives. Pp. 339-352 in *Brassica oilseeds: Production and Utilization* (Eds D.S.Kimber and D.I.McGregor), CAB International/Cambridge University Press, Cambridge.

STAFFORD, J.A., NORTON, G., SCOTT, R.K., STOKES, D.T., DOUGHTY, K.J. and RUSSELL, P.K. (1995). Effects of prochloraz on the physiology of oilseed rape. *Proceedings of the GCIRC Ninth International Rapeseed Congress, Cambridge, UK,* **2**, 512-514.

SWEET, J.B., KNIGHT, C., POPE, S.J. and SPARKS, T. (1989). Disease resistance and fungicide response in oilseed rape varieties. *Aspects of Applied Biology* **23**, 427-437.

UPPSTRÖM, B. (1995). Seed chemistry. Pp.217-242 in *Brassica oilseeds: Production and Utilization* (Eds D.S.Kimber and D.I.McGregor), CAB International/Cambridge University Press, Cambridge.

WARD, K., SCARTH, R., DAUN, J.K. and VESSEY, J.K. (1995). Chlorophyll degradation in summer oilseed rape and summer turnip rape during seed ripening. *Canadian Journal of Plant Science* **75**, 413-420.

WILMER, J.A., HELSPER, J.P.F.G. and VAN DER PLAS, L.H.W. (1996). Effect of growth temperature on erucic acid levels in seeds and microspore-derived embryos of oilseed rape (*Brassica napus* L.). *Journal of Plant Physiology* **147**, 486-492.

**Published Articles relating to the project**

"Oil quality study shows light leaf spot poses greater risk" *Farming News* April 19th 1996, pp. 26-27.

Doughty, K.J., Lewis, C.A., McCartney, H.A., Norton, G.,.Booth, E.J. and Walker, K.C. (1996) Oilseed rape yield and quality in relation to fungal disease. *Proceedings of the Fourth European Society of Agronomy Conference, Wageningen, 7-11 July 1996, pp540-541.*

Doughty, K.J., Norton, G., Lewis, C.A. and McCartney, H.A. (1996) A pilot study of the effect of disease on seed quality parameters of oilseed rape. *Home Grown Cereal Authority Report OS11/1/94*, 33pp.

Doughty, K.J., Lewis, C.J., McCartney, H.A., Norton, G., Booth, E.J., & Walker, K.C. (1997) Fungal disease induced changes in oilseed rape (*Brassica napus* L) seed quality: implications for the crop protection of future "industrial" cultivars. In: *Domestication, Production and Utilisation of New Crops*, Eds. J. Smart and N. Haq, Centre for Under Utilised Crops, Southampton, pp279-280.

Doughty, K.J., Landon, G., McCartney, H.A., Norton, G., West, G., Booth, E.J., Walker, K.C. Kightley, S.P.J. & Thomas. J.E. (1997) Fungicide use and oil quality in rapeseed (*Brassica napus* L). In: *Crop Protection and Food Quality: Meeting Customer Needs,* Proceedings of a Conference, Canterbury, 17-19 Sept. 1997, British Crop Protection Council and l'Association Nationale de Protection des Plantes, pp 451-456.

9: APPENDIX 1. Trivial names of fatty acids referred to in the text.

| | |
|---|---|
| 14:0 | Myristic acid |
| 16:0 | Palmitic acid |
| $16:3^{\Delta 7, 10, 13}$ | Hexadecatrienoic acid |
| 18:0 | Stearic acid |
| $18:1^{\Delta 9}$ | Oleic acid |
| $18:2^{\Delta 9, 12}$ | Linoleic acid |
| $18:3^{\Delta 9, 12, 15}$ | Linolenic acid |
| 20:0 | Arachidic acid |
| $20:1^{\Delta 11}$ | Eicosenoic acid |
| $22:1^{\Delta 13}$ | Erucic acid |