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STATUS OF DISEASES OF LINSEED IN THE UK

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by

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Abstract

Linseed is a rapidly expanding crop in the UK, with an area fast approaching 120,000 ha, making the UK the biggest producer of linseed in Europe.

A range of 15 pathogens, with the potential to cause disease problems in the UK, has been selected, their symptoms described, their present status in the UK evaluated and possible control measures outlined.

The most important are believed to be:

(i) *Alternaria linicola* (seedling disease)
(ii) *Fusarium* spp. (seedling disease)
(iii) *Botrytis cinerea* (grey mould)
(iv) *Oidium lini* (powdery mildew)

The first three are mainly seed-borne and can cause problems with seedling emergence, leading to a poor stand. The level of seed-borne disease varies from year to year, ranging from only 22% of seed infected in 1990 (a dry year) to 98.4% in 1987 (a wet year). *A. linicola* is by far the most important, followed by *F. avenaceum* and *B. cinerea*. Seed-borne diseases can be controlled by seed-treatment, although there have been resistance-problems with some of the fungicides used. Some research has been targetted towards control of seed-borne diseases by application of sprays to the growing crop. Results have been variable, but it appears as if better control is likely to be achieved in the SE of England.
Oidium lini causes powdery mildew and its level also varies from year to year, being worse in dry years. It is also worse in drier parts of the country, such as the SE of England. It can be controlled by resistant cultivars and fungicide sprays.

A number of other pathogens, such as *Phoma exigua* f.sp. *linicola*, *Sclerotinia sclerotiorum*, *Fusarium oxysporum* f.sp. *lini and Verticillium dahliae*, has also caused problems from time to time, but so far not on a widespread scale.

Because of the small size of linseed leaves, problems arise with the estimation of various diseases in linseed crops. These are outlined.

The process of seed-certification is described and problems associated with interpretation of the rules are discussed.

Some trials have been undertaken to investigate cultivar effects on disease resistance. Differences between cultivars were observed in responses to *A. linicola*, *B. cinerea*, *O. lini* and *S. sclerotiorum*, although it is not always clear how much effect is due to inherent resistance and how much to differences in maturity.

A small section is concerned with the effects of disease on oil quality and quantity. At present there appears little impetus to breed for improvement in these parameters as no minimum standards are laid down by the crushers. This may, however, change in the future. Generally there seems little problem with the quality of linseed oil from UK crops.

Seed-producers were asked for their perceptions of disease problems and a summary of these is included. Generally their reports supported research findings in that *A. linicola* and *B. cinerea* were considered to be the most important diseases. *O. lini* was thought of as a problem in dry years, but it was not clear if it was always economic to use sprays to control it. Surprisingly there was little comment on the *Fusarium* spp. involved in seedling disease, although this may be because many seed-firms have only become substantially involved with linseed in the last few years; the last year with high levels of *Fusarium* spp. was 1987.

The Review concludes with recommendations for future research.

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Glossary of terms

Alternaria spp.:	group of fungi, one of which, *Alternaria linicola*, causes a seedling disease.
Aureobasidium lini:	fungus causing stem-break or browning. Also known as *Polyspora lini*, *Kabatiella lini* or *Discosphaerina fulvida*.
Botrytis cinerea:	fungus causing a seedling disease and grey mould of capsules.
capsule:	part of linseed plant holding the seed.
Chalara elegans:	see *Thielaviopsis basicola*.
Colletotrichum linicola:	fungus causing a seedling blight. Also known as *Colletotrichum lini*.
conidiophore:	part of fungus bearing conidia (asexual spores)
cotyledons:	two "seed leaves" at the base of a seedling stem.
cultivar:	cultivated variety.
Discosphaerina fulvida:	see *Aureobasidium lini*.
embryo:	potential plant found in the centre of the seed.
epidemiology:	study of factors affecting the outbreak and spread of plant diseases.
f.sp.:	abbreviation for *forma specialis*, a variant of a species.

fungistat:	material preventing growth of a fungus, but, unlike a fungicide, not killing it.
Fusarium spp:	group of fungi, including *Fusarium oxysporum* f.sp. *lini* which causes a wilt and *Fusarium avenaceum* which causes damage to seedlings.
hyphae:	microscopic strands which make up a fungus.
Kabatiella lini:	see *Aureobasidium lini*.
Linum usitatissimum:	flax or linseed. Both are one species, although their forms are different. Flax is grown largely for fibre, although seed can be harvested. Linseed is grown almost entirely for seed.
Melampsora lini:	fungus causing rust.
mycelium:	mass of fungal hyphae.
Mycosphaerella linicola:	fungus causing Pasmo disease. Sometimes also known as *Septoria linicola*.
Oidium lini:	fungus causing powdery mildew. Sometimes also known as an *Erysiphe* sp.
pathogen:	organism, such as a fungus, capable of causing disease.
perithecium:	microscopic fungal fruiting structure, often flask-shaped, containing spores which have been produced sexually.
Phoma exigua var. *linicola*:	fungus causing foot rot.

Pleospora herbarum: seed-inhabiting fungus, largely harmless in nature. Also known as *Stemphylium botryosum*.

Polyspora lini: see *Aureobasidium lini*.

pycnidium: microscopic fungal fruiting structure, often flask-shaped, containing spores which have been produced asexually.

Pythium spp: group of fungi causing scorch and damping-off.

Rhizoctonia solani: fungus causing a root disease of flax.

saprophyte: organism, such as fungus, growing on dead plant material.

Sclerotinia sclerotiorum: soil-borne fungus which can attack linseed as well as a range of other crops including oilseed rape.

sclerotium(a): dark, hard, resistant structure(s) of fungi such as *Botrytis cinerea* and *Sclerotinia sclerotiorum*, which allow the pathogens to remain viable in the soil for many years.

Septoria linicola: see *Mycosphaerella linicola*.

sp., spp.: singular and plural abbreviations of the word species.

spore: microscopic structure by which a fungus is dispersed.

Stemphylium botryosum: see *Pleospora herbarum*.

Thielaviopsis basicola:	soil-inhabiting fungus causing a root rot. Also known as *Chalara elegans*.
Verticillium dahliae:	fungus causing a desiccation of linseed plants.

Introduction

The area of arable land being sown to linseed in the UK has increased exponentially in the last 7 years (Fig. 1) and is now approaching 120,000 ha, making the UK by far the largest producer within Europe. Romania is the second largest producer with 50,000 ha. Linseed is a crop that has relatively low inputs, is not in surplus within the EC and attracts a relatively generous area subsidy. The nucleus of growth has been in East Anglia, but in the last few years the crop has been spreading out and there is now a large area of linseed in Yorkshire with small but increasing areas in Scotland, Wales and Northern Ireland. One of the main problems with the crop is the potentially late harvest, which can be delayed until the end of October, although the warm summers of recent years have tended to obscure this fact. There is a move to breed earlier-maturing cultivars, but it will be some years before these come through into commercial production. However, the seed-heads, unlike those of oilseed rape, remain fairly intact and there is little shedding of seed. Late harvesting is not therefore such a risk from the point of view of yield loss. On the other hand, the longer the crop remains standing in a mature state, the greater the chance that the seed will become infected with seed-borne pathogens. These, although not generally damaging, will affect germination and consequently will be a problem for crops grown for seed.

Seed-borne diseases, in particular that caused by *Alternaria linicola*, are probably the main disease problem facing the linseed grower, although the recent dry seasons have also seen quite a high level of powdery mildew on leaves and stems. However, linseed has only been grown on a large scale relatively recently and it is possible, indeed probable, that not all potential disease problems have yet declared themselves. In trying to write a review on the status of diseases of linseed within the UK, cognisance has to be taken of disease status in Europe. Disease status in other linseed-growing countries, such as India, Canada and the Soviet Union, may also be important in assessing the risk to the UK crop of diseases which are currently not found to any great extent. This information, plus the recent advisory and research experience of the authors in the UK, has led to the selection of a range of fifteen known and potentially-damaging fungal pathogens for consideration. This is not to say that other disease problems may not surface over the next few years as the area of linseed increases further and farmers are tempted into growing linseed on the same land for more than one year; virus and bacterial diseases are not, for example, mentioned at all. However, the authors feel that the pathogens described should include most of the main disease problems likely to be encountered within the next few years by the UK linseed grower. Although some diseases are currently more important in the UK than others, they are, for ease, arranged alphabetically by their Latin names.

Individual diseases

Alternaria spp.

Distribution and disease status.

The main species found on linseed in Britain, and the most important of all the seed-borne pathogens, is *Alternaria linicola* (Mercer, McGimpsey, Black & Norrie, 1985). Indeed, since the expansion of the linseed area in UK, infection by *A. linicola* has been the main reason for the failure of seed-samples to reach certification standards (see also pp. 38-40; Figs. 8-11). Two other *Alternaria* spp., *A. alternata* and the *Alternaria* state of *Pleospora infectoria* are also found on seed, but are not generally pathogenic. A further *Alternaria* sp. is described from India as *A. lini* (Dey, 1983; Arya & Prasada, 1953), although it is not clear from its description whether it really is a separate species or a type of *A. alternata*. On the other hand the symptoms accorded to it are quite unlike those associated with *Alternaria* spp. in the UK. Whether this is due to climatic differences or differences between species or types is uncertain. It is therefore difficult, at present, to assess any potential threat from the Indian *Alternaria* to the UK linseed industry, although it is probably better to err on the side of caution and avoid importation of Indian linseed for sowing. A further *Alternaria* sp., *A. cheiranthi* has been isolated from fibre flax in the Ukraine (Grebenyuk, 1983), but not from any other linseed or flax-growing areas.

Alternaria linicola

Symptoms and life cycle.

Although not highly pathogenic to adult plants, *A. linicola* can cause severe damage to seedlings, attacking them as they emerge from their seed-coats. The attack results in the formation of brick-red lesions on stems and roots (although these can also be a symptom of attack by other pathogenic fungi). Seedlings may be seriously weakened or killed and this may result in a substantial reduction in plant stand (Mercer, McGimpsey & Ruddock, 1989).

The epidemiology of the pathogen is not clearly understood, as little disease can be discerned on the growing crop apart from a few dark-brown lesions on cotyledons and lower leaves early in the season. However, as the crop comes close to harvest and the capsules begin to change colour, they can become infected very quickly by *A. linicola* (Fig. 2). This occurs most rapidly in a season with a wet period before harvest, *eg*. Figs. 8-11. It appears that sufficient inoculum exists on the lower leaves for it to multiply quickly when conditions are suitable. Certainly, spore numbers have been observed to increase markedly just prior to capsule infection (Fig. 3). However, in a dry season, such as 1989 in England, the level of *A. linicola* was often very low (Figs. 12-13); under even drier conditions, as in the following year, many crops had none at all (Figs. 14-15).

The pathogen appears to infect the seed through the capsule wall and, under damp conditions, will colonise the outer layer of the seed-coat, where it forms resting hyphae. There is a very strict demarcation between the seed-coat and the rest of the seed in that only under exceptional circumstances will the pathogen colonise the embryo. Although the level of *A. linicola* on seeds is known to decrease with time, this can be very slow compared with other seed-borne pathogens (Fig. 4) and appears to vary with samples. Although germination may improve for a while (Fig. 5) due to the dying-out of the pathogen, it could, by loss of natural vigour, be well below certification limits by the time the incidence of the pathogen had fallen to the 5% certification standard.

Control measures.

The most effective method is by the use of seed-treatment, which can control even levels of 100% of *A. linicola* and lead to an increase in emergence and stand count (Fig. 6). There is, however, a suspicion that this may be a fungistatic rather than a fungicidal effect, as *A. linicola* can be isolated early in the season from lower leaves even when seeds had been treated (Mercer *et al.*, 1989). The most effective product, currently recommended, is prochloraz (Prelude, Schering Ltd.). Iprodione (Rovral, Rhone-Poulenc Ltd.) may, on occasions, also be effective, but considerable problems have arisen in recent years with high levels of resistance to this product by

A. linicola (Mercer, McGimpsey & Ruddock, 1988; Fig. 7).

Several research workers have attempted to control *A. linicola* in the field by the use of fungicidal sprays. This work has produced mixed results. Mercer and his co-workers in Northern Ireland found little evidence of control with a single spray application (1989; 1990), although multiple (but uneconomic) applications were found to reduce the level of *A. linicola* in the seed (Mercer, McGimpsey & Ruddock, 1991). Hardwick & Mercer (1989), in the North of England, found differences in ripening following the use of sprays, and some effect on yield (probably due to control of *Botrytis cinerea*), but no effect on the level of *A. linicola* in the seed. On the other hand, Fitt and Ferguson (1990), found a relatively good level of control in the S.E. of England in 1988 and 1989, although not quite down to the level that would have been required for certification. Further work is required in this area, but it is likely that that a spray would be effective only in the drier areas of the UK . Even there, because of the tendency of seed-producers to apply seed-treatment even to relatively disease-free seed (to provide customer reassurance), a yield benefit following spray application would also have to be demonstrated.

Rather surprisingly, sprays of iprodione seem more effective in reducing levels of *A. linicola* on seed than sprays of prochloraz, even where resistance to iprodione exists (Mercer *et al.*, 1991).

There is some evidence for cultivar resistance (Scurtu, 1987; Mercer & Jeffs, 1988; see also p. 42), although this is compounded to some extent by differences in cultivar maturity.

Aureobasidium lini
(*Discosphaerina fulvida*, *Kabatiella lini*, *Polyspora lini*)
(Stem-break, browning)

Distribution and disease status.

A. lini is world-wide in distribution. It was described by Petrie (1974) as the commonest seed-borne pathogen of linseed in Canada. Plonka & Anselme (1956) reported losses of 15% in flax fibre due to the pathogen. They also noted that it could attack linseed. Although it is seed-borne *A. lini* has not yet been discovered in seed-certification samples in the UK. As with some other potential pathogens, it is unclear whether this is because insufficient linseed is yet grown, whether it has yet to be re-introduced (it was known in the past in N. Ireland (Muskett & Colhoun 1947)), or whether growing seasons have not yet been suitable for its multiplication.

Symptoms and life cycle.

Although the pathogen may attack at the seedling phase, especially if the weather is warm and wet, the severity of the attack is usually insufficient to kill the plant. Evidence of the pathogen's presence is seen in the form of dark, water-soaked lesions on the cotyledons, which remain stuck to the plant and provide a good inoculum source for attacks about 7-8 weeks after sowing. These produce stem lesions which cause a local weakness and frequently lead to a break, hence one of the common English names. The lesions may also act as an entry-port for other pathogens, such as *Fusarium* spp.

As the crop approaches harvest, the upper parts of the plant become covered with long brown spots, giving patches of the crop a bronzed or browned appearance, hence the other common English name. Browning tends to be worse when the temperature is above 16° C and humidity above 90% (Schrödter & Hoffman, 1961). Although browning may reduce seed-yield, its main importance is that it is during this period that the pathogen enters the seed via the capsule.

The disease is more severe in the thick and lush crops produced on rich and heavy soils.

Control measures.

Crops which have been sown earlier and therefore harvested earlier tend to have less browning. A certain level of cultivar resistance also appears to exist, at least among flax cultivars (Marchenkov, 1987; Beaudoin, 1989). However, the most important control measure is believed to be the maintenance of disease-free seed (Muskett & Colhoun, 1947).

Botrytis cinerea
(grey mould)

Distribution and disease status.

B. cinerea was the most common disease problem reported in a survey of linseed growers in England and Wales in 1988, with 33% of crops affected (Giles, 1990). At present *B. cinerea* is one of the few linseed pathogens in the UK whose control by fungicidal sprays has shown a yield benefit (see p. 15).

B. cinerea is reported as attacking leaves, stems and capsules (Muskett & Colhoun, 1947; Houston, 1940) and may cause significant losses, particularly when the weather during and after flowering is wet, such as occurred in the UK in 1987 and 1988. In a dry season, such as 1989 or 1990, the incidence of *B. cinerea* on linseed crops is insignificant. It can also be an important seed-borne pathogen. Van der Spek (1965) suggested that infected seed was the major source of the disease in the Netherlands. In France, up to 24% of the flax-growing area may be affected with levels of up to 80% infection on the seed (Anselme & Champion, 1964). In the UK, *B. cinerea* is usually ranked after *Alternaria linicola* and *Fusarium avenaceum* on linseed seeds (P.C. Mercer & H.C. McGimpsey, unpublished; Figs. 8-11), although it was the commonest pathogen in 1990, a year in which there were generally very low levels of seed-borne diseases (Figs. 14-15). UK legislation requires that less than 5% of seed is contaminated by *B. cinerea* for a crop to be certified for use as seed (Anon., 1985).

Symptoms and life cycle.

If infected seed is planted and weather conditions favour disease development, the first symptoms are seen shortly after emergence as a reddish-browning on plant stems close to ground level. Plants then collapse, die and become covered with a characteristic grey mould consisting of fungal mycelium, conidiophores and spores. Spread of the disease is encouraged by warm, moist conditions and if these occur at seedling emergence then large areas of plants (Muskett & Colhoun, 1947), even on occasions the whole crop (Plonka & Anselme, 1956), may be killed. Although cold, dry weather can impede the spread of disease completely, alternating wet and dry periods encourage the disease, as the wet periods favour the formation of spores while the dry ones favour their dispersal.

B. cinerea does not generally infect crops after the seedling stage if growing conditions are good, but can cause problems in very dense or lodged crops, or crops where there was an excessive nitrogen input. Where infection does occur, striking white lesions are frequently found on the stems. Such lesions are found more frequently on fibre flax, which is sown more densely than linseed, after it has been desiccated by glyphosate (Bratt, Mercer & Brown, 1988). The strength of fibres from lesions is up to 15 times less than that of fibres from uninfected stems (Mercer & Fraser, 1986). This lack of strength frequently results in stem breakage (Beaudoin, 1989). In stems with established infections, grey mycelium of *B. cinerea* frequently covers the lesion and eventually hard, black sclerotia are produced. Sclerotia of *B. cinerea* on linseed are flattened and mainly on the stem surface, by contrast with those of *Sclerotinia sclerotiorum* which form within stem tissue (de Tempe, 1963). These sclerotia can survive on debris and contribute to the survival of the pathogen. *B. cinerea* can also survive on many other hosts since it has a wider host range than any other plant pathogen in the UK (Anon., 1984) and can exist as a saprophyte on dead and decaying plant parts.

Frequently crops which have no *B. cinerea* on their stems develop symptoms on the seed capsules, especially when the weather during flowering is wet (Rawlinson & Dover, 1986). Individual capsules are covered with conidiophores and spores which give them a grey furry appearance. It is possible that the floral tissues become infected by the pathogen during flowering and that the infection remains latent until the capsule reaches a certain stage of maturity (Jarvis, 1977). Infection by *B. cinerea* at the capsule stage has been associated with dead petals which readily become infected (Muskett & Colhoun, 1947). The incidence of the pathogen in the crop does not always appear to be reflected in its incidence on the seed; it is thought that the fungus is partially eliminated by the infected capsules falling to the ground before or during harvesting. This loss of infected capsules may contribute to the yield losses attributed to *B. cinerea*. The relatively low levels of *B. cinerea* in seed appear to decline rapidly compared with those of *Alternaria linicola* (Fig. 4)

Control measures.

B. cinerea is readily controlled on the seed by treatments containing prochloraz or carbendazim-generating (MBC) fungicides (Maddens, 1987; Mercer, McGimpsey & Ruddock, 1988). However, development of resistance to MBC fungicides is common in populations of *B. cinerea* (Leroux & Clerjeau, 1985). As the disease may be spread by the inclusion of sclerotia in the seed (McKay, 1947), good cleaning will help to keep the amounts of inoculum low. The use of fungicide sprays (carbendazim or iprodione) in linseed crops has been shown to decrease the incidence of *B. cinerea* on capsules from 4 to 1% and to increase the yield of seed (Turner, 1987; Hardwick & Mercer, 1989). Avoidance of excessive levels of nitrogen and high populations of plants will also help to reduce potential problems in the growing crop. Some cultivars are more susceptible to attack than others (Plonka & Anselme, 1956) (see also p. 42).

Colletotrichum linicola

(Seedling blight)

Distribution and disease status.

Seedling blight is caused by the fungus *Colletotrichum linicola* (also known as *Colletotrichum lini*). It has been recorded in nearly every country where *Linum usitatissimum* is grown either for fibre or oil. Although it can attack the adult plant, *C. linicola* is primarily a disease of seedlings. Apart from one incident of crop loss with imported seed (Rawlinson & Dover, 1986), *C. linicola* is currently found only infrequently on seed samples in the UK (P.C. Mercer & H.C. McGimpsey, unpublished), although Vakhrusheva & Nikitina (1979), in the USSR, ranked it first in frequency of isolation from flax-seed. The disease can produce appreciable crop losses. Muskett & Colhoun (1947) recorded a loss of 50% in fibre yield on flax in an epidemic year in Northern Ireland and McKay

(1947) noted it as the most common disease of flax in the Republic of Ireland. Because of its past importance, *C. linicola* is obviously a pathogen to be kept under observation. The reason for its current low incidence is unclear, although it may be related to cultivar resistance (see p. 17).

Symptoms and life cycle.

As with several other pathogens of linseed, *C. linicola* is carried over in the seed in the form of resistant hyphae embedded in the outer layers of the seed coat. When the seed starts to germinate, the outer layer absorbs water and the hyphae start to grow and produce spores which can then infect the emerging seedling if conditions are warm and moist. Cotyledons are attacked and within a few days become reddish brown and dry out. If the growing point is attacked then the whole plant will be killed. If the plant is attacked but survives it is likely to be weak and spindly. Stems may be infected by spores, washed down from the leaves, and also show the reddish brown lesions typical of linseed which has been attacked by a variety of other pathogens. Ondrej (1985) indicated a considerable loss in fibre strength following an attack by *C. linicola.* Stems affected in this way will eventually produce fruiting structures containing masses of pink spores. The seed is attacked via the capsule wall and the central stalk of the capsule. Fallen petals will encourage the initial growth of the fungus. Capsules of lodged crops are more liable to be attacked than those of unlodged crops. It is generally considered that *C. linicola* is spread via the seed, but it is also a possibility that plants become infected from the soil.

The effects of *C. linicola* tend to be worse in warm, wet weather. Certain cultivars and late-sown and lush, thickly-growing crops are also more susceptible. Laciowa (1978), working on fungal communities in soil from flax fields, found that crops with the wilt pathogen *Fusarium oxysporum* f.sp. *lini* tended to have lower levels of *C. linicola*.

Control measures.
Seed treatments are the most effective method of control. Rotation and the removal of crop residues will also reduce the risk of the pathogen being picked up from the field. Early and even sowing may also restrict the spread of disease (Muskett & Colhoun, 1947; Ambrosov & Neofitova, 1978). There is also a wide range of cultivar diversity in resistance to *C. linicola* (Popisil, 1976) and this is frequently incorporated into breeding programmes (Karpunin & Rogash, 1984). This perhaps accounts for the fact that *C. linicola* is an infrequent pathogen on current cultivars in the UK, although it used to be one of the commonest when flax-growing was at its height. However there is also a degree of specialisation on the part of the pathogen and several races may exist (Zarzycka, 1976). This capacity for race variation may eventually result in the breakdown of resistance in current cultivars. However, if this does occur, fungicide seed-treatments should provide control of the seed-borne phase of the disease.

Fusarium spp.

Species of *Fusarium* have caused problems in recent years where successive crops of linseed have been attempted and especially in the hot dry summers of 1989 and 1990. However, apart from the detailing of seed-borne infection (Mercer & McGimpsey, 1987) few data are available on the effect of the diseases caused by *Fusarium* spp. in the UK.

There is a number of species of *Fusarium* that infect linseed and, as with *Alternaria* spp., a certain amount of confusion appears to exist on the identification and role of various *Fusarium* spp. Most workers are agreed that the main *Fusarium* pathogen is *Fusarium oxysporum* f.sp. *lini* (sometimes referred to as *F. lini*). On the other hand, Ondrej (1977), in Czechoslovakia, described *Fusarium* diseases as a complex, with different *Fusarium* spp. present at different stages - *F. avenaceum* (also known by the name of another stage of the fungus - *Giberella avenacea*) at the beginning, *F. oxysporum* f.sp. *lini* at flowering and *F. avenaceum* and *F. equiseti* (also known as *Giberella intricans*) at ripening. A similar complex was also described from the USSR by Korneeva & Korshunova (1973). As well as these clearly pathogenic fusaria there also appears to be a range of semi-parasitic or non-pathogenic *Fusarium* spp. (Turner, 1987). Detailed description is restricted to *F. avenaceum*, *F. culmorum* and *F. oxysporum* f.sp. *lini*.

Fusarium avenaceum

Fusarium avenaceum can cause damping-off of seedlings under UK conditions (H. C. McGimpsey and P. C. Mercer, unpublished) and, in some years is second in importance only to *Alternaria linicola* (Figs. 8-11). In Russia, Vakhrusheva & Nikitina (1979) found *F. avenaceum* to be one of the more frequent pathogens in a survey of seed-borne diseases. Andruszewska (1977), in Poland, reported attacks by *F. avenaceum* and *F. culmorum*, which caused rots of the root collar in the early stages of development. Ondrej (1983), in Czechoslovakia, successfully inoculated flax plants in the field with inoculum of *F. avenaceum*. However, in other areas where *Linum usitatissimum* is grown there are very few references to this particular organism. Under the microscope, spores of *F. avenaceum* are characteristically sickle-shaped (Sutton, 1971). In France *F. roseum* (also known as *F. acuminatum* or *Gibberella acuminata*) is given a position similar to that of *F. avenaceum* in the UK (Beaudoin, 1989). The pathogen can be controlled on the seed by the use of prochloraz or MBC - generating fungicides (Mercer & McGimpsey, 1987; Mercer, McGimpsey & Ruddock, 1988). However MBC resistance in *F. avenaceum* has been reported in Czechoslovakia by Pavelek (1983) and Ondrhacetej (1985). The incidence of *F. avenaceum* on seed decreases rapidly with time, little remaining one year after harvest (H.C. McGimpsey, pers. com.).

Fusarium culmorum

Like *Fusarium avenaceum, F. culmorum* can be found as a seedling pathogen, reducing stand counts (P.C. Mercer & H.C. McGimpsey, unpublished). It can also be found as a secondary organism, invading tissue following damage by pathogens such as *Aureobasidium lini* or *Melampsora lini* (Muskett & Colhoun, 1947). It has powerful cellulolytic properties (Brown & Sharma, 1984) and can seriously damage stems (Sharma, 1986). Affected areas of the stem have a reddish-pink colouration and typical sickle-shaped *Fusarium* spores can be seen under the microscope. An attack by *F. culmorum* will tend to accelerate the senescence already induced by organisms such as *M. lini*. Apart from the use of seed-treatments to control the seed-borne phase, primary control of *F. culmorum* is not a practical proposition. However, emphasis should be placed on reducing predisposing factors, such as attack by *M. lini* and *A. lini*.

Fusarium oxysporum f.sp. *lini*.
(wilt)

Distribution and disease status.

Fusarium oxysporum f.sp. *lini*, commonly known as flax wilt, occurs in most countries in which *Linum usitatissimum* is grown. In France, it is the main plant pathological problem affecting the flax crop (Beaudoin, 1989). Krylova & Voronova (1981), in the USSR, reported that 66% of flax crops were affected annually by *F. oxysporum* f.sp. *lini* and that, at the time of writing, none of the 20 cultivars grown was immune. In the Rajasthan area of India, Sharma & Mathur (1971) reported 87% of linseed crops affected. Although *F. oxysporum* f.sp. *lini* has been reported at a low level in the UK (Rawlinson & Dover, 1986), and is thought unlikely to become generally serious in most years because of its relatively high temperature requirement (McKay, 1947), there have been a few serious local outbreaks, *eg*. two instances in Hampshire in 1990 (D.R. Jones, pers. com.). In one case the crop followed linseed, but in the other it followed cereals.

Symptoms and life cycle.

Symptoms are typically of a wilt. Plants may be attacked from the seedling stage onwards although usually, more severe attacks occur around mid-June (Plonka & Anselme, 1956). The first sign of disease is a droop followed by death of the upper leaves and growing point. The leaves of affected plants turn brown and the whole plant eventually senesces prematurely. Fungal fruiting structures are formed at the stem base and, under the microscope, can be seen to contain the characteristic sickle-shaped cells of a *Fusarium* sp. Damage varies from slight, when only a few individual plants are affected, to the almost complete death of the crop. Bhargava &

Shukla (1980) have also noted infection by *F. oxysporum* f.sp. *lini* to cause a reduction in the yield of oil.

Tu & Cheng (1976), in China, have reported up to 6% transmission of *F. oxysporum* f.sp. *lini* by seeds. However, it is generally believed that the disease largely spreads via the soil where propagules of the fungus can remain viable for up to 28 years in the absence of *Linum usitatissimum* (Martin, Leonard & Stamp, 1976). A high inoculum of the pathogen can build up on land which has grown *Linum usitatissimum* for a number of years and it then becomes 'flax-sick'. Even in the absence of the pathogen, strong toxic effects on flax by water extracts from 'flax-sick' soils have been reported by Sysoenko (1972). However, the crop may escape severe attack, even in heavily contaminated soil, if the weather conditions are not optimal (temperatures of between 25° and 30°C and a damp environment (Lemaire *et al.*, 1982; Beaudoin, 1989)). A drought following infection will produce more serious symptoms than if moist conditions persist. Lemaire *et al.* also reported that the fungus was rare in soils where the pH was greater than 6.8. Shawish & Baker (1982) suggested that the disease may be worse when the crop has been continuously bent by the wind.

Control measures.

F. oxysporum f.sp. *lini* is not easily controlled by the use of fungicidal sprays. However, any transmission of the pathogen via the seed may be controlled by seed-treatments such as prochloraz or MBC-generating fungicides (Mercer & McGimpsey, 1987; Mercer, McGimpsey & Ruddock, 1988). Apart from rotation, which can be of limited value, because of the longevity of the pathogen in the soil, the only effective means of control is by the use of resistant cultivars (Rowland & Bhatty, 1987; Beaudoin, 1989). So far, resistance to *F. oxysporum* f.sp. *lini* seems to be stable, but with more intensive cultivation of resistant cultivars the situation may eventually change, especially as Portyankin, Terekhova & Levitin (1988), in the USSR, have shown the pathogen to be highly variable. This makes it more likely that more pathogenic forms of the fungus could arise. However, breeding programmes, aimed at the production of new resistant cultivars, are being carried out in a number of countries eg. the USSR (Ambrosov & Neofitova, 1978), Argentina (Acosta & Marinesco, 1980) and Canada (Rowland, Kenaschuk & Bhatty, 1990a; 1990b).

Although the use of sprays is not particularly effective, Prasad (1979) found that the addition of a solution containing zinc could reduce the severity of wilt. A possibility for biological control also exists. The way in which *F. oxysporum* f.sp. *lini* interacts with other soil microorganisms has been studied extensively (Laciowa, 1978; Arora,1980) and there has also been a lot of work on what are known as "suppressive soils". These are soils which tend to limit the disease. Although certain soil-types appear more suppressive than others (Tu & Cheng, 1982), the presence of antagonistic microorganisms such as non-pathogenic *F. oxysporum* (Tamietti & Alabouvette, 1986) or the bacterium, *Pseudomonas putida* (Scher & Baker, 1982) is probably also important. Akhtar, Amin & Salim (1982) found that flax wilt in Pakistan could be reduced by the addition of the fungus *Aspergillus flavus* to the soil. There is then, the possibility that such antagonistic microorganisms may eventually form the basis of commercial biological control preparations.

Other *Fusarium* spp.

Apart from the three species of *Fusarium* described, there is a considerable number of *Fusarium* spp. which have been associated with *Linum usitatissimum* - *F. equiseti*, *F. lateritium*, *F. moniliforme*, *F. semitectum*, *F. solani* and *F. acuminatum* (Turner, 1987). All may cause damping-off under excessively damp conditions and they may also be associated with secondary damage to stems in the field following attack by other organisms. Control is by avoiding conditions favouring growth of the microorganisms.

Melampsora lini
(rust or firing)

Distribution and disease status.

Rust of linseed is generally accepted as being caused by *Melampsora lini*, although Bedlan (1984), in Austria, has described two

Melampsora spp., *M. liniperda* and *M. lini*, distinguished by the size of their spores or spore cases. *M. lini* is, at present, uncommon in the UK, although it has been noted from most countries of the world where *Linum usitatissimum* is grown. In the USSR over 40% of the USSR crops were reported to be infected by rust annually (Krylova & Voronova, 1981). In India *M. lini* occurs practically everywhere that linseed is cultivated (Gill, 1987), greatly reducing the quantity, but not the quality, of the oil. Weather conditions in the UK would appear to be suitable for the spread of rust, so it is not clear why the disease is at present uncommon. It may be a combination of the lack of intensive cultivation until recently and cultivar resistance.

Symptoms and life cycle.
The first sign of *M. lini* is usually in early summer (Turner, 1987) Scattered orange pustules are observed on the green parts of the plant. These contain spores which are carried by wind to infect other plants. Later in the season, elongated, slightly-raised, black incrustations appear on the main stem, branches, leaves and capsules at the site of the pustules (Muskett & Colhoun, 1947). Plants appear as if they had been burnt, hence the popular name of 'firing'. Inside the incrustations are resistant, thick-walled spores which help the pathogen to survive the winter. These spores usually germinate the following spring, although occasionally it may be two years before this occurs. Germination results in the production of a complex of different fruiting structures and spore types which infect other plants, thus completing the life cycle of the pathogen.

A light attack may not affect the crop greatly, but a heavier attack can cause the leaves to be shed. When black incrustations are produced the stem can become weakened. Damage caused *M. lini* tends to be worse where crops are late-sown and where the soil has a high level of nutrients. In the USSR, Karpunin (1981) reported that the disease tended to be worse in years with a lot of rain. In India, over 60% of the variation in incidence of *M. lini* could be explained by weather factors (Saharan & Singh, 1985).

Control measures.

M. lini does not infect the seed, in the way that *Alternaria linicola* and *Fusarium avenaceum* do. However, it can be carried along with the seed in the form of incrustations from crop fragments. Cleaning the seed thoroughly will therefore tend to reduce carry-over. Agrawal & Kotasthane (1970), in India, recommended the use of mercurial seed-dressing to prevent carry-over, but this option is not available in the UK. The most effective method of control is probably cultivar resistance and several countries include this factor in their breeding programmes, eg. Czechoslovakia (Ondrej, 1978); the USSR (Krylova & Voronova, 1981); India (Prasad, Rai & Kerkhi, 1988); Canada (Rowland *et al.*, 1990a; 1990b); and France (C. Sultana, pers. com.). However, as with many other instances of breeding for resistance, there are various races of the pathogen. Misra, Kamthan & Shukla (1990), for example, in India, reported work in which seven races of *M. lini* were used and Beaudoin (1989) reported the presence of two races in France. Beaudoin also stated that no chemical control of *M. lini* was possible, although work on the control of cereal rusts would tend to cast doubt on this. Furthermore, Thakore, Sneh Mathur & Singh (1987), in India, reported control of *M. lini* with 0.05% tridemorph. Sowing early (Boguslawski, 1960) and avoiding high levels of nitrogen will also reduce its severity.

Mycosphaerella linicola
(*Septoria linicola*)
(Pasmo)

Distribution and disease status.

The disease popularly known as Pasmo is found in most regions of the world where *L. usitatissimum* is grown and particularly on linseed rather than fibre cultivars. Although it had been reported from the Republic of Ireland by Loughnane, McKay and Lafferty in 1946 it was not noted from the rest of Ireland or Britain until 1975 when Holmes (1976) observed it in Scotland on a linseed trial. In 1985 it was found attacking a crop in N. Yorkshire and in 1986 reported on a linseed cultivar in a mixed linseed/flax trial in Northern Ireland (Mercer & Brown, 1986). In both cases it is fairly certain that the pathogen was introduced via infected seed. However, although there have been no further observations, the threat of a serious attack must remain.

Symptoms and life cycle.

The first sign of attack, that most farmers will be aware of, usually occurs just before harvest. Areas of the crop very quickly become brown. Although it is the stems that are initially attacked, the disease spreads to leaves, causing defoliation, and eventually also on to the capsules, possibly suppressing seed-formation (Bedlan, 1984). All affected areas are light-brown in colour and contain minute, dark coloured fruiting bodies (pycnidia and perithecia). The disease is favoured by warm weather, heavy dew and periodic rainfall (Tsvetkov, 1980).

Control measures

Deep ploughing, removal of crop debris and rotation will all help to lower the disease level. It may be possible to use chemical seed-treatment to cut down on that means of transmission, although the pathogen appears to be much more deep-seated in the seed than *Alternaria linicola* and therefore more difficult to eradicate (Turner, 1987). Sprays of mancozeb and benomyl, in early stages of development of the crop, have been shown to have some effect in Russia (Batalova & Kumacheva, 1983) and in the USA (Ferguson, Lay & Evenson, 1987), although it is probable that a large spraying programme would not be economic under UK conditions. Evidence in the literature for effective cultivar resistance is rather sparse although P.C. Mercer and H.C. McGimpsey (unpublished) in Northern Ireland have shown significant differences between cultivars at the seedling stage.

Oidium lini

(Powdery mildew)

Distribution and disease status.

This disease was widespread on UK linseed crops in 1990 when the summer was dry, but was much less common in 1988, when the summer was wet (Giles, 1990). It is generally assumed that *O. lini* causes little damage in the UK (Rawlinson & Dover, 1986), although a 10%

yield response to fungicide treatments in 1990 experiments at Rothamsted was associated with control of *O. lini* (Fitt & Ferguson, 1990). Furthermore, *O. lini* can cause serious damage in India (Pavgi & Singh, 1965) where it is regarded as the second most important disease, after *M. lini* (rust) (Saharan, 1990). When *O. lini* infects linseed before flowering, yield reduction of up to 10% due to reduced numbers of seed per capsule and shrivelled seed have been observed (Spencer, 1978).

Symptoms and life cycle.

An attack by *O. lini* produces the typical appearance of a powdery mildew, frequently completely covering plants with white powdery pustules, containing the mildew spores, on both surfaces of leaves, stems and capsules. Spores, which are easily dispersed by the wind, can be seen under the microscope, either singly or in chains (Muskett & Colhoun, 1947). With a heavy attack, the whole plant will turn yellow, although it may not be very easy to see underneath the pustules and spores (McKay, 1947). Epidemics develop rapidly and airborne spore concentrations as great as 2200 spores/m^3 have been observed above UK linseed crops during epidemics (Fitt & Ferguson, 1990). *O. lini* requires high humidity for initial infection but is spread much more readily in warm, dry conditions (Plonka and Anselme, 1956). The disease, like other powdery mildews, tends to be worse on lush crops.

In North America a sexual form of the pathogen has been observed on crops late in the growing season (Allison, 1934). This may have some relevance in the development of variation which could produce more pathogenic races of *O. lini*. Elsewhere in the world only asexual spores (conidia) have been observed. In Europe, where the sexual form of the pathogen has not been found, it is assumed the fungus overwinters as mycelium and conidia. There appears to be some confusion about the identity of the sexual form of *O. lini*, which has been variously described as *Erysiphe lini*, *E. cichoracearum* (Allison, 1934) and *E. orontii* (Ing, 1990). Several workers (Spencer, 1978) stress that *O. lini* should not be regarded as specific to linseed. Ing (1990) suggested that *E. orontii* can attack a wide range of plants, including evergreen species, and that these might provide alternatives for overwintering.

Control measures.

In 1990, in trials by NIAB on two sites, the incidence of *O. lini* ranged from 90% for early maturing cultivars like Antares and Norlin, to as little as 15% in the very late maturing cultivar Beryl (R.E. Beale, pers. com.; see also p. 43). It is not clear whether these observations reflect true differences in resistance between cultivars or only differences in susceptibility related to the stage of maturity of the plants. However, resistant cultivars are known to exist elsewhere. Several have, for example, been identified in field trials in India (Rai 1990, Saharan 1990). Resistance is controlled by a single dominant gene (Singh & Saharan, 1979) and is correlated with high hydrocyanic acid content (Pandey, Kush & Mishra, 1981). Although some cultivars are resistant to both *M. lini* and *O. lini* (Misra & Pandey, 1981), most which are resistant to *O. lini* are highly susceptible to *M. lini* and *vice versa* (Saharan, 1990).

Resistance is the easiest way to control the disease, although the level of *O. lini* is not always high enough to be worth considering control, at least in Europe (Turner, 1987; Beaudoin, 1989). Control by fungicides has been shown to be effective in India (Sharma & Khosla, 1979) and in the UK where fungicide sprays reduced the incidence of *O. lini* on *cv.* Antares at late-flowering from 100% to 47% and also greatly reduced the severity of the disease (Fitt & Ferguson, 1990). The best control of *O. lini* in susceptible cultivars is probably obtained by using fungicide sprays containing tridemorph, propiconazole or triadimefon.

Phoma spp.

Distribution and disease status.

Foot-rot symptoms ascribed to *Phoma* spp. have been reported from most of the areas of the world where *Linum usitatissimum* is grown. When flax was grown on a widespread scale in Ireland in the 1940's and 50's, attack by *Phoma* spp. was considered to be one of the most serious disease problems limiting production (H.C. McGimpsey, pers.

com.). McKay (1947), also in Ireland, reported a build-up in severity over the same period resulting in epidemic conditions. Possibly because of the extended gap when no linseed or flax was grown in the UK and possibly also because of the recent dry seasons, the level of disease attributed to *Phoma* spp. has been low. On the other hand, in France, with a much longer history of flax and linseed growing, Sultana (1983) reported yield losses in excess of 30%.

As with *Alternaria* spp., there is still some confusion over the identity of *Phoma* spp. associated with *L. usitatissumum*, although this problem was noted almost 45 years ago (Muskett & Colhoun, 1947). Three distinct *Phoma* spp. have been isolated from *L. usitatissimum* in Northern Ireland (P.C.Mercer & H.C. McGimpsey, unpublished). One of these was highly pathogenic and was recognised as *P. exigua* var. *linicola*. The other two remain unidentified, although one was not pathogenic. Other workers, such as Breyer (1963), in Germany, have also discovered more than one *Phoma* spp. However, for the purposes of this review, it is assumed that the main *Phoma* sp. attacking *L. usitatissimum* in UK is *P. exigua* var. *linicola*.

Phoma exigua var. *linicola*
(foot rot)

Symptoms and life cycle.

Although Muskett & Colhoun (1947) and Reeder & Vanterpool (1953) indicated that *P. exigua* var. *linicola* is soil-borne, the pathogen can also be carried on the seed (Vakrusheva & Nikitina, 1979), where, like *Alternaria linicola*, it is found as resting hyphae in the outer skin of the seed coat. If the seed is untreated, the pathogen will emerge on germination and attack the seedlings at soil level, causing browning of roots and stems, yellowing and wilting of the leaves, and eventually, death of the plant. If *P. exigua* var. *linicola* attacks later, light brown lesions are found on stems about 1 cm above the soil and typically 2-5 cm long, though they may cover the whole stem. Plants affected in this way will senesce prematurely and are often in patches throughout a field. The lesions usually contain the tiny, black fruiting bodies (pycnidia) of the fungus, which can be seen by eye, but are more readily seen with a hand-lens. The disease tends to be worse in very wet seasons (Brown & Mercer, 1985), perhaps one reason why it has not been observed very frequently in the UK in recent years. This could well change if seasons are wetter; if the linseed area continues to increase; and particularly if farmers are tempted to go for more continuous cropping.

Control measures.

P. exigua var. *linicola* can be controlled at the seedling stage by seed-treatment (Maddens, 1987; Mercer, McGimpsey & Ruddock, 1988). Later, however, control becomes much more difficult. Muskett & Colhoun (1974) recommended the use of rotation to avoid the build up of inoculum in the soil. There also appears to be some variation in resistance among cultivars, *eg*. cv. Atalante appears to be more susceptible to attack than *cvs*. Antares or Lidgate (Mercer & Jeffs, 1988).

Pleospora herbarum
(*Stemphylium botryosum*)

Although Mahdi, Satour & Shiltawy (1973) observed that nearly all seed samples tested in the UAR contained *P. herbarum*, there are few other references to this fungus in the literature. On the other hand it is quite frequently found in seed samples from UK linseed (P.C. Mercer & H.C. McGimpsey, unpublished). However, it appears to have a status rather similar to that of *Alternaria alternata* and *Pleospora infectoria*, *ie*, basically a saprophyte, but with a low level of pathogenicity in some circumstances, when there might be a very restricted effect on stand (P.C. Mercer & H.C. McGimpsey, unpublished). It is controlled by any of the seed treatments used against *A. linicola* and is not thought likely to cause major disease problems.

Pythium spp.
(damping-off/scorch)

Linseed diseases caused by *Pythium* spp. are known from Europe, North America and Australia. There appear to be two main sets of symptoms attributable to *Pythium* spp., namely damping-off, caused by a number of *Pythium* spp. and scorch, caused by *Pythium megalacanthum*. There is no information on the incidence of *Pythium* spp. in the UK in recent years.

Damping-off

Damping-off is caused by a number of *Pythium* spp. *P. debaryanum*, *P. aphanidermatum* and *P. irregulare* (Plonka & Anselme, 1956) have all been isolated from flax seedlings which had been killed before emergence. If the attack is less virulent, the reddish brown colouration, typical of host response to attack, is seen on the young stems and roots. Moderate damage to the root system may lead to the production of secondary roots. The *Pythium* spp. responsible are soil-inhabiting fungi and a microscopic examination of the roots will generally show the presence of characteristic spores of the fungus. The disease tends to be favoured by cold weather in spring, wet, acid soil and deep sowing.

Scorch

Scorch, caused by *Pythium megalacanthum*, normally appears in late spring or early summer as patches of stunted plants with leaves shrivelled on the lower half of the stem. The most severely affected plants die, but less affected ones can recover if favourable growth-conditions occur (Muskett & Colhoun, 1947). The fungus attacks the roots on which spores can usually be seen under the microscope. The disease is worse with cold, wet spring weather and in early-sown crops. Unlike with damping-off, alkaline conditions tend to encourage the disease. *P. megalacanthum* may persist in the soil for at least twenty years (Muskett & Colhoun, 1947). In France Beaudoin (1989) has observed a complex of pathogens, including *Asterocystis radicis*, *Thielaviopsis basicola* and *P. megalacanthum*, causing the same sort of symptoms.

Control measures.

Seed-treatments can assist in control, even though the pathogen is not seed-borne (Muskett & Colhoun, 1947). Turner (1987) recommended the use of thiram. Michail *et al.* (1975) indicated benomyl to be superior to thiram in Egypt. The use of lime in acid soils can also help to alleviate symptoms. Scorch can be controlled by the same fungicide treatments as recommended against damping-off. In addition, a degree of cultivar resistance has been reported (Plonka & Anselme, 1956; Anon, 1972).

Rhizoctonia solani

Distribution and disease status.

R. solani (also referred to as *Corticium solani* and *Thanatephorus cucumeris*) has been recorded in Europe, North America, India and Kenya as a cause of disease on flax. It also occurs on various weeds and crop plants (Krylova, 1981), although strains exist and the strain on potatoes in Ireland is not the same as the one on flax (McKay, 1947). *R. solani* is now thought of as a group species, *i.e.* it exists in a number of genetically different forms. This has significance for plant breeders who must determine the composition of isolates with which to challenge new lines. *R. solani* isolates can be grouped according to their ability to fuse (anastomose) their mycelium with the mycelium of another isolate. Those closely related will tend to anastamose, while those not closely related will not. These groupings are referred to as "anastomosis groups" (AG's). There are currently about 12 AG's with AG 1 and AG 2 further divided into two sub-groups. AG's have been reviewed by Anderson (1982), who concluded that it is important to consider each AG as an individual unit so that progress can be made in devising control methods. Commonly AG 1 occurs on cereals and AG 3 on potatoes. AG 2 and AG 4 predominate on oilseed rape (Hwang, Swanson & Evans, 1986). AG 4 has been shown to infect the stems of flax seedlings while AG's 2 and 3 have produced a limited rotting of the roots (Anderson, 1982).

Considerable losses in yield have been recorded in the USA (Brentzel, 1923). On the other hand Asthana (1956), in seed-inoculation experiments in India, found *Fusarium* spp. to be about seven times more effective at inducing wilting than *R. solani*. The potential of *R. solani* to damage in linseed in the UK is not yet known. Although no reports of damage have been received in the last few years, its ability to cause damage in the past should counsel caution.

Symptoms and life cycle.

Symptoms are not unlike those caused by *Thielaviopsis basicola*. The first indications of disease are small brown lesions on the roots just below the soil surface. Later these lesions expand both upwards to the cotyledons and downwards towards the root tips, to produce a total affected length of up to 4-5 cm. Later the tissue is reduced to a dry pulp which may break and split to give a ragged appearance. Plants affected in this way may wither and senesce prematurely. They may also break at the soil surface when pulled. It is possible for large patches of plants to be affected (Brentzel, 1923) or for single plants to be affected at random (McKay, 1947). *R. solani* is generally transmitted through the soil.

Control measures.

As *R. solani* is mainly soil-borne, fungicide treatment in the field is unlikely to be successful. The most effective control measures are good crop hygiene and rotation. Resistance is also known in several countries - Poland (Sadowski, 1972); the USSR (Krylova, 1981); and the USA (Anderson, 1977, 1982). Treatment of seeds with preparations containing thiram, was shown to reduce disease severity in Egypt in soils which had been artificially inoculated (Michail *et al.*, 1973). El-Nawawy *et al.* (1973), also in Egypt, showed that the level of *R. solani* could be reduced by the application of growth-regulating compounds. Biological control has also been partially successful. Cheng & Tu (1974) used the fungus-eating nematode *Aphelenchus avenae* to produce some control. Brown (1987) was also able to reduce the level of *R. solani* by applying spores of the fungus *Zygorrhynchus moelleri*.

Sclerotinia sclerotiorum

(stem rot)

Distribution and disease status.

Sclerotinia stem rot, caused by the soil-borne fungus *Sclerotinia sclerotiorum*, has been reported as attacking *Linum usitatissimum* in Europe, the USA and the USSR. Mitchell, Jellis & Cox (1986) recorded the disease in England and noted an incidence of up to 15% in one field in Herefordshire. In spite of the potential of *S. sclerotiorum* for causing severe crop loss, if the same pattern is followed as for the diseases it causes in other crops in the UK, it is likely to be severe only in the occasional crop. It is not thus, at present, considered a major threat to UK crops. *S. sclerotiorum* is not specific to linseed, but is capable of attacking a wide range of field crops such as carrots, sunflowers, potatoes, peas, winter field beans and oilseed rape, as well as a number of weed species (Hims 1979).

Symptoms and life cycle.

The disease usually occurs in small patches with affected plants generally attacked near ground level, where water-soaked lesions are produced (Mitchell *et al.*, 1986). Plants attacked in this way either senesce prematurely or lodge. Sometimes, the lesions may be higher up the stem (McKay, 1947) and if this is so the upper part of the stem will begin to die and ultimately break off. White, compact fluffy mycelial growth can be seen on the surface and inside stems, and eventually this becomes associated with the production of hard, black sclerotia. They differ from those of *Botrytis cinerea* in that they are larger and more globose (Muskett & Colhoun, 1947).

S. sclerotiorum, like many other sclerotial fungi, is capable of surviving in the soil for a prolonged period (Turner, 1987), especially if the sclerotia are buried deeply. If they are buried more shallowly they will germinate relatively readily if temperature and soil moisture are suitable. This is usually in the summer when buff-coloured fruiting bodies (apothecia) are produced. These resemble small toadstools and are about 8 mm in diameter. They contain spores which are shot out under pressure and are spread by wind to infect other plants.

Wet conditions and lush crops grown on heavy, rich land tend to favour the disease. *S. sclerotiorum* is also more likely to occur when wet weather coincides with flowering so that fallen petals stick to leaves and stems where they provide a suitable food-base for the fungus (Lamarque, 1983).

Control measures.

Some differences in resistance between cultivars have been reported

(Sweet, 1991 and p. 43). Since the disease occurs on a wide range of alternative break crops, such as potatoes and oilseed rape, care should be taken in the choice of rotation. However, previous cropping is not necessarily an indication of risk. Karpunin (1981), in the USSR, found the disease to be worse following clover and potatoes, but McKay (1947), in Ireland, noted that the disease in flax following a crop of infected potatoes was not always as severe as might have been expected.

Good control of the disease by fungicides is possible. Turner (1987) reported trial results indicating that a spray containing iprodione, vinclozolin or prochloraz would provide control of *S. sclerotiorum*. Although the disease is not known to be seed-borne, sclerotia can contaminate seed lots from affected crops (Mitchell *et al.*, 1986). Yarham & Giltrap (1989) suggested that certification standards should include maximum limits on contamination by sclerotia and sclerotial fragments of *S. sclerotiorum*. Routine methods for control are unlikely to be necessary.

Thielaviopsis basicola
(Chalara elegans)
(root rot)

Distribution and disease status.

T. basicola has been noted from Europe, the USSR and the USA, but its status is not completely clear. It is a ubiquitous soil inhabitant and attacks the roots of a large number of plants. In France (Beaudoin, 1989) it is associated with two other fungi - *Pythium* sp. and *Plasmodiophora brassicae*. However, the symptoms described correspond closely to those observed by both McKay (1947) and Muskett & Colhoun (1947) to be caused by *T. basicola* alone. It has not been reported from UK linseed crops in recent years, although again this may merely be a matter of intensity of cultivation.

Symptoms and life cycle.

The first indications of disease come when patches of seedlings (*c*. 10 cm high) become pale and stunted and start to wither from the top. If plants are pulled out and the roots examined it will be observed that they are few in number and blackened. Spores are thick-walled and very resistant, surviving in the soil for prolonged periods. In France the pathogen appears to be more damaging in light soils in coastal areas (Beaudoin, 1989). When flax was grown on a large scale in Ireland, the disease was only perceived as a problem when the crop was grown continuously (McKay, 1947). Although transmission of the pathogen seems to be largely through the soil there is one reference (Schilling, 1925) to its also being seed-borne.

Control measures.

Rotation and the control of high weed populations appear to be the most effective methods of control. There is also a suggestion of cultivar resistance (Beaudoin, 1988).

Verticillium spp.

Distribution and disease status.

Although both *V. albo-atrum* (Turner, 1987) and *V. dahliae* (Fitt & Ferguson, 1990) have been reported to occur in UK linseed crops (the latter probably back as far as 1988), the pathogens are not usually considered of economic importance (de Tempe, 1963) because symptoms appear only sporadically as crops approach maturity. *V. albo-atrum* is not usually regarded as pathogenic to *Linum usitatissimum*. *V. dahliae*, on the other hand, has caused wilting and death of young fibre flax plants during stem extension in May-June (Marchal, 1940) and mycelium and microsclerotia of *V. dahliae* were abundant in the roots of these plants. Marchal (1940) and Hoffmann & Rondomanski (1959) were able to demonstrate the pathogenicity of *V. dahliae* to fibre flax by reproducing in pot experiments the symptoms which had been observed in field crops.

Symptoms of verticilliosis caused by *V. dahliae* were widespread in experimental plots in the UK and Germany in 1990 as crops approached maturity (Fitt *et al.*, 1991). These observations may have been associated with the expanding area of the crop (Fitt and Ferguson, 1990) and with the exceptionally hot weather which occurred in the UK in the summer of 1990, since *V. dahliae* is favoured by high soil temperatures (Schnathorst, 1981).

Symptoms and life cycle.
Symptoms of verticilliosis (Fitt *et al.*, 1991) are grey chlorotic or brown stripes on green stems, or dark-brown stripes on maturing light-brown stems. Symptoms frequently extend along the whole length of the stems and branches up to the capsules, and often spread completely round the stems. Black microsclerotia develop abundantly in stems with these symptoms and *V. dahliae* can be consistently isolated from them. In trials at Rothamsted, UK, the incidence of verticilliosis increased from 50 to 100% in untreated plots (*cv.* Antares) between 8 and 22 August and ranged from 49 to 98% on cultivars and breeding lines in trials at Thule, Germany on 9 September. Affected stems were brittle and broke easily. When affected plants were pulled up, white mycelium was present at the stem base. The incidence of *V. dahliae* was, respectively, 4, 4 and 13% on capsule cases, sepals and seeds from unsprayed plots and 0, 3 and 3% on capsule cases, sepals and seeds from plots treated with fungicides at Rothamsted.

In several successive years, fibre flax crops in Germany developed verticilliosis late in the season but symptoms were of progressive desiccation rather than of wilting (Hoffman and Rondomanski, 1959). Patches of plants with grey discoloured stem and branch tissue up to the flower head occurred in crops after flowering. Affected plants frequently had extensively damaged root systems and weakened stem fibres. Numerous microsclerotia of *V. dahliae* were observed inside the stem.

Synergistic effects between *Verticillium* spp. and the nematode *Pratylenchus penetrans* have been observed and plant growth has been improved by the addition of a nematicide in pot experiments (Coosemanns, 1979).

Control measures.
It is unclear whether the source of inoculum in UK linseed crops is soil-borne or seed-borne (Fitt *et al.*, 1991). Although *V. dahliae*

has been isolated from seed samples, seed-borne inoculum is usually regarded as unimportant for *V. dahliae* (de Tempe, 1963). It is possible that soil-borne inoculum might remain from previous susceptible crops such as linseed, sunflowers and potatoes, as it is known that microsclerotia of *V. dahliae* can survive in soil for several years (Schnathorst, 1981). Even if *V. dahliae* is not generally damaging to linseed crops, the longevity of soil-borne inoculum and the experimental observations referred to above, suggest that the occurrence of this pathogen on linseed should be taken into account when planning crop rotation.

Disease Assessment

The habit of the linseed plant and the life-cycles of some diseases that attack the crop makes assessment difficult.

Diseases that are restricted to roots, stems and capsules present little difficulty, but two of the major pathogens, *Botrytis cinerea* and *Alternaria linicola*, do present problems.

The leaves of linseed are small and strap-like and lesions tend to occupy a major part of the leaf, frequently causing total senescence. Diseases tend to occur in patches in the crop and on the plant, and do not necessarily infect at the base of plant and progress to the top like many cereal diseases.

No standard assessment keys exist, and no detailed methodology for sampling in preparation for disease assessments has yet been prepared. It is important to standardise assessment methods in disease control experiments. Work is required in order to establish protocols for disease assessment.

Seed Treatment and Certification in the UK

Seed-borne disease status and statutory requirements.

Seed-borne diseases are potentially the biggest disease problem currently faced by growers of linseed in the UK (Mercer & Hardwick, 1990). Because of the very dry summers of the last few years seed-borne diseases have been at a low level, and there is a danger of underestimating the problem. The occurrence of a wet season such as 1985 would almost certainly result in very high levels of seed-borne diseases, threatening seedling vigour and plant stand.

The major seed-borne pathogen is *Alternaria linicola* (Figs. 8-15), followed by *Fusarium avenaceum*, *B. cinerea* and *Phoma exigua* var. *linicola*. To be sold as seed, linseed must attain certain levels of germination and seed hygiene (Anon., 1985). The level of germination required is 85%. Pathogens are divided into two groups - *Botrytis cinerea*, whose incidence must not exceed 5%, and the rest, identified as *Alternaria* spp., *Fusarium oxysporum* f.sp. *lini*, *Colletotrichum linicola* and *Phoma exigua* var. *linicola*, whose combined incidence may not exceed 5%. These standards have been set for historical reasons and currently appear rather arbitrary.

The procedure for testing linseed seed for pathogens.

Random samples of seed are taken and placed on malt agar in Petri dishes (10 seeds per dish). For certification purposes 400 seeds are tested, but advisory samples provide a good guide as to disease status with as few as 100 seeds. The dishes are placed in an incubator, at 20° C, for 5 days if the sample is untreated and for 7 days if the sample has had a seed-treatment. The dishes are also subjected to a light regime of 12 h dark; 12 h near-ultra-violet light, which encourages any organisms present to produce spores which are a major aid in identification. At the end of the incubation period the dishes are examined under a stereo microscope and the incidence of each of the pathogens estimated.

Experience of seed-testing for disease in the UK

In practice, in the UK, the incidence of *B. cinerea* does not often exceed 5%. *Alternaria* spp. are, at present, taken to refer solely to *A. linicola*, because of the minimal pathogenicity of the other *Alternaria* spp. The incidence of *A. linicola* may range from 0% in a dry season (Figs. 12-15) to 100% in a wet one (Figs. 8-11). *F. oxysporum* f.sp. *lini* has very rarely been encountered on UK linseed and the category has been enlarged to include the undoubted pathogen, *F. avenaceum*, (and occasionally *F. culmorum*) which can be relatively common in a wet year, although the incidence is usually considerably less than *A. linicola* (Figs. 8-15). There is also an interaction between *A. linicola* and *F. avenaceum* in that the presence of *A. linicola* tends to suppress *F. avenaceum* which may only be detected if a seed-treatment, such as iprodione, which controls *A. linicola*, but not *F. avenaceum*, is applied (Mercer & McGimpsey 1985). This can result in a much higher incidence of *F. avenaceum* being expressed than was evident before treatment. *Phoma exigua* var. *linicola* and *Colletotrichum linicola* have only rarely been found in UK linseed samples (Figs. 8-15).

As observed earlier (p. 10) the level of seed-borne disease declines with time, the decline being very slow for *A. linicola* but fairly rapid for the other pathogens. Interactions, like that between *A. linicola* and *F. avenaceum*, may also occur between pathogens and non-harmful fungi such *Epicoccum nigrum* (Mercer, McGimpsey and Ruddock 1990). This can lead to problems in assessing levels of pathogens because these may appear to rise, as non-harmful fungi which are exercising a measure of control, tend to die out faster than the pathogens (P.C. Mercer & H.C. McGimpsey, unpublished).

Control of seed-borne diseases.

Because the embryo is rarely attacked by seed-borne pathogens (see p. 10), the potential for control by seed-treatment is high. The most commonly-used seed treatment, at present, is prochloraz (Prelude, Schering Ltd.) which will control all the main pathogens, reducing even very high levels of contamination to below 5%. It is recommended for all current cultivars, with the exception of cv. Linda, where it causes problems with the sticking together of the cotyledons. Iprodione (Rovral, Rhône Poulenc Ltd) can also be effective against *A. linicola*, except where fungicide resistance occurs. It is also not effective against *F. avenaceum* and the addition of benomyl (Benlate, DuPont Ltd.) is required if this is present.

Concern has been expressed about the dangers of resistance arising to prochloraz and whether or not possible replacements exist. At present there is no obvious resistance to prochloraz among linseed pathogens and, judging from experience with fungicides with the same mode of action, if it did occur, would be likely to occur over a fairly long time-scale. On the other hand, none of the fungicides tested so far appears as effective as prochloraz while at the same time being relatively non-phytotoxic.

Breeding for disease resistance

The following summary is based on a number of cultivar trials carried out by NIAB over several years, the examination of advisory seed samples and also on a research programme which examined resistance to *Sclerotinia sclerotiorum.*

Plant breeding objectives.

Plant breeders are principally aiming to improve the earliness of varieties without reductions in yield, so that the crop can be grown more widely in UK. Shorter growing seasons with harvest in late summer rather than autumn would reduce levels of disease on capsules and seed. However, many of the earlier varieties are likely to have reduced height, with short internodes and capsules nearer to the ground, which could encourage the development of certain diseases.

Shorter growing seasons would also increase the effect of foliar disease on yield, so that resistance to diseases such as powdery mildew would become more important. Good understanding of disease development and crop damage is needed so that decision-making for appropriate control strategies can be improved.

Plant breeders are also seeking to modify the chemical composition of the linseed plant so that it can be used for both industrial and animal and human nutritional purposes. Diseases that reduce oil quality, especially if they affect its nutritional status, could become more important in the future (see p. 44).

Winter hardiness genes are present in some *Linum* species and could be transferred to northern European linseed varieties. However, this is some way off and is not likely to have an impact on linseed developments in the near future.

Disease resistance to individual pathogens.

Alternaria linicola

Leaf and capsule infection of linseed cultivars seems to be closely related to environmental conditions and maturity, with late maturing and lodged varieties having higher levels of infection. However, some differences have been observed between cultivars.

Levels of seed-borne infections are frequently high, especially after wet seasons. Different levels of *A. linicola* have been found on seed of cultivars from NIAB trials, though how much this is due to maturity/cultivar interactions is not known. Levels of seed-borne *A. linicola* are sometimes enhanced by fungicide treatment of the seed crop.

Botrytis cinerea

Records from cultivar trials have shown small differences in infection levels, though these cannot, at present, be distinguished from maturity effects. Studies of seed from NIAB trials have indicated different levels of infection in seed of different cultivars, but again this may also be related to cultivar maturity at harvest. Badly lodged crops and wet conditions favour the disease, so that standing ability of cultivars is an important factor.

B. cinerea has been found frequently in advisory seed samples and high levels of *B. cinerea* have developed on autumn-sown linseed. Resistance by *B. cinerea* to MBC-fungicides and to iprodione has been noted in other crops, *eg*. Leroux & Clerjeau (1985); Davis & Dennis (1981) (see also p.15).

Fusarium spp.

Suggestions of different levels of *Fusarium* spp. on seed of different cultivars in UK have been noted by P.C. Mercer & H.C. McGimpsey (unpublished) and differences in cultivar resistance to soil-borne *Fusarium* infection have been recorded in Canada (Rowland, Kenaschuk & Bhatty, 1990a; 1990b). Soil-borne *F. oxysporum* f.sp. *lini* infections are more a feature of hot, dry climates, or close rotations. The only consistent reports of infection in the UK have come from sites in Southern England growing continuous linseed in poorly-drained soil.

Oidium lini

Differences in disease levels have been observed in cultivar trials. Later-maturing cultivars tended to have less disease than earlier-maturing cultivars. Of the earlier-maturing cultivars, McGregor appears to be more resistant than Amazon, Atlante, Antares or Norlin. The late-maturing cultivar Blue Chip seemed more resistant than Beryl or Linda.

Powdery mildew appears to reduce the photosynthetic area of plants significantly, resulting in earlier senescence and ripening of seed. Yield losses are presumed to be due to this earlier ripening. On a trial near Cambridge run by BASF, yield responses of up to 18% were achieved when fungicidal control of powdery mildew markedly reduced senescence and premature ripening.

The resistance of cultivars with similar levels of maturity requires further investigation. Responses of varieties to fungicides will be investigated in the HGCA-funded NIAB cultivar x fungicide trials.

Sclerotinia sclerotiorum

S. sclerotiorum has occasionally been reported in the UK. Three per cent of plants developed disease in a NIAB trial in Sussex. Differences between cultivars confirmed results of artificial inoculation studies carried out at Cambridge. Experience with other crops indicates that lodged crops of linseed are likely to be very susceptible to mycelial spread of *S. sclerotiorum*.

Other pathogens (*Phoma, Colletotrichum, Mycosphaerella, Aureobasidium*)

A range of other diseases has been reported in crops and seed samples, but not at appreciable levels. The significance of these diseases in the UK in relation to yield, quality and seed transmission is not known. Some resistance to *Colletotrichum linicola* (seedling blight) has been recorded.

Effects of disease on oil quality and quantity

(prepared with the assistance of Mr M. Hyndley of BOCM Silcock Ltd.)

There are a few references in the literature to the effects of disease on the quantity and quality of linseed oil following disease. Plonka & Anselme (1956) in France noted a reduction in both of about 10% following an attack of *Mycosphaerella linicola* (Pasmo). Gill (1987), in India, noted a greatly reduced quantity but not quality in oil following attack by *Melampsora lini* (rust). Bhargava & Shukla (1980) reported a reduction in oil quantity following attack by *Fusarium oxysporum* f.sp. *lini* (wilt). More references appear to be concerned with the effect of agronomic factors such as addition of fertiliser, water and herbicides.

UK linseed, according to the crushers, provides a good quality oil, with a content ranging from *c.* 33-39%. One factor which can reduce the oil content is overheating during drying. Although old contracts between crushers/merchants and producers did not stipulate a minimum oil quantity for seed, future ones, based on Federation of Oil Seeds and Fats Associations (FOSFA) oilseed rape contracts, will include, amongst other things, a requirement for a minimum of 35%. At present, loads of seed for crushing are accepted or rejected largely on grounds of general appearance. Marinescu, Doucet & Popescu (1988), in Romania, referred to the selection of linseed cultivars for higher oil content, but so far this has not been a criterion for UK breeders.

Although there is no quality criterion applied to producers, the linseed oil itself must conform to British Standard BS243/632 1969, which indicates a minimum iodine value (a measure of its drying properties for use in paints) of 175. There is, however, some presure to reduce this figure to 160. Oils with higher iodine values are considered to be better for paint production. There tends to be a climatic difference in iodine values in that those from oil produced in countries such as Argentina, south of the equator, lie in the range 175-185, while those from countries, such as Canada and Europe, north of the equator, lie in the range 185-192. European oil should, therefore, have an advantage for use in paints.

Cake, produced as a by-product of crushing, has, unfortunately, a fairly low energy content, and has to compete in the animal feed market with cheap "fillers" such as imported tapioca.

Summary of comments by UK seed producers

A circular letter was sent out to all the major producers of linseed seed within the UK, asking for their comments on what they considered to be the main disease problems within the UK industry. Replies were received from 9 companies and the following is a summary of the main points (numbers in brackets refer to individual companies which are listed following the summary):

1. *Alternaria linicola* and *Botrytis cinerea* were perceived as the main disease problems. There was a realisation that the situation could be considerably worse if there were a return to wetter seasons such as 1987.

2. *Oidium lini* was perceived as a problem in the recent dry years, particularly on cv. Antares, although doubts were cast on the economics of fungicide sprays to control it (5, 8). One producer (7) commented on the use of resistant cultivars to control the disease.

3. *Fusarium oxysporum* f.sp. *lini* was noted by two producers (1, 7) as being a problem where there was continuous cropping, with the concern (7) that this may become a worse problem with susceptible cultivars, hot, dry summers and more intensive cultivation. Other *Fusarium* spp., causing seedling disease, were only referred to by one producer (3), although it is known that some companies have had problems with *Fusarium* sp. contamination in the past.

4. Two producers (1, 9) referred to *Phoma* foot rots, damping-off diseases and *Pythium* (scorch). Although they did not comment on their present status, one (1) indicated that he thought that these diseases were likely to increase in severity with increased cropping.

5. Most of the seed companies recommended treating seed with prochloraz fungicide to control seed-borne diseases, although two (7, 8) commented on the occasional reduction in germination; one (7) suggested that the loading rate of prochloraz could be reduced for smaller-seeded cultivars. Although there had been some early

problems in drilling with this seed-treatment (2, 4), as seeds tended to be sticky, it is considered that this has now been largely overcome. Because of the current highly effective nature of seed treatment, one producer (3) questioned the requirement for disease-testing of treated seed. On the other hand, another seed-producer (4) felt there should be a move towards zero tolerance of disease on seed, something which could not be guaranteed by seed treatment (see Figs. 8-9).

6. One producer (4) was concerned at the lack of effective alternatives to prochloraz if fungicide-resistance problems were to occur.

7. Opinions seemed to be mixed on the question of spraying fungicides on the growing crop for the control of *Alternaria linicola* and *Botrytis cinerea*. Some felt that current products were insufficiently effective to guarantee an economic return (6). Others (*eg*. 2) felt that yield increases could be obtained, especially with control of *B. cinerea*. Some (*eg*. 2) felt it was important to apply fungicides to reduce the level of disease in seed. It was recognised that research was required in the whole field of formulations, rates and timings of fungicide sprays.

8. Several producers recommend rotations for disease control. One (2) insists on at least a two-year break from any cruciferous crops, presumably to reduce the danger of attack by *Sclerotinia sclerotiorum*.

List of seed companies who responded to request for information

1.	Banks of Sandy Ltd.	29 St. Neot's Rd., Sandy, Bedfordshire SG19 1LD
2.	Sharps International Ltd.	Boston Rd., Sleaford, Lincolnshire NG34 7HH

3.	British Seed Houses Ltd.	Portview Rd., Avonmouth, Bristol BS11 9JH
4.	Goreham Bateson Ltd.	Border House, Fordham, Downham Market, Norfolk PE38 0LW
5.	International Seed Producers	Tayfen Rd., Bury St. Edmunds, Suffolk IP32 6BH
6.	Semundo Ltd.	Unit 55, Clifton Rd., Cambridge CB1 4FR
7.	John Turner (Arable Consultant)	The Mews Close, 22 Cromwell Rd., Ely, Cambridgeshire CB6 1AS
8.	Velcourt Ltd.	Manor Farm, 20 Back Lane Collyweston, Stamford, Lincolnshire PE9 3PW
9.	Waveney Seeds Ltd.	Chickering Hall, Hoxne Eye, Suffolk IP21 5BT.

Recommendaticns for research

Seven areas for further research have been identified, together with indications of sources of funding. In many areas several possible sources of funding have been noted and it is suggested that joint funding of certain projects would be most appropriate. The HGCA component would be aimed at producing crops with low, integrated inputs, which would enhance the reputation linseed already has of being "environmentally friendly". This would be achieved by paying more attention to the incidence of diseases, their effect on yield components and their control by the most effective means, be it cultivar, fungicide, cultural or a combination of all three.

1. SURVEYS

These are essential for the provision of basic knowledge on the incidence of diseases of linseed in the UK, both regionally and seasonally. Diseases can be divided into those of the growing crop and those carried by the seed.

Growing crop: At present, annual surveys of oil-seed rape are supported by Policy Divisions of MAFF. It is envisaged that MAFF would support similar surveys of linseed diseases. Surveys should be extended to Scotland and N. Ireland.

Seed: Information is available from data-bases created by DANI and NIAB for seed-analyses. These will continue to be valuable sources of basic information on the extent of seed-borne diseases.

R & D Priorities

(i) Surveys of crops and seed to be conducted throughout UK.
High Priority (MAFF/DANI/SOAFD)

(ii) Monitoring of resistance of seed-borne pathogens to fungicides.

Medium Priority (HGCA/DANI/Commerce)

2. SEED-BORNE DISEASES

Seed-borne diseases are a major factor in the rejection of crops for the purposes of seed-production. Further R & D is required on:

the interaction, on seeds, between different pathogens and between pathogens and non-pathogens; and the effect of fungicides on individual populations of pathogens and non-pathogens. This would assist in the determination of appropriate fungicidal control measures.

the current standards for seed-certification. These appear rather arbitrary and not particularly applicable to the UK, *eg.* with respect to *Fusarium* spp.

alternative chemical and/or biological treatments for the control of pathogens on seed. Seed treatments on linseed are at present limited to two active ingredients, prochloraz and iprodione.

R & D Priorities

(i) Study of microbial ecology of seed.

High Priority (HGCA/DANI)

(ii) Reappraisal of current seed-certification standards

Medium Priority (HGCA/DANI/EC)

(iii) Investigation of alternatives to present seed-treatments.

Medium priority (Commerce)

3. **YIELD & DISEASE**

Comparatively little is known about the effects of any disease on the components of yield. A study of this area would allow an assessment of the economic importance of the various pathogens. Further R & D is needed on:

effects of pathogens on components of grain and oil yield.

R & D Priorities

(i) Production of protocols for the sampling of diseased material and the assessment of disease incidence.

High Priority (HGCA/MAFF)

(ii) Studies of disease/yield-loss relationships for *Alternaria linicola*, *Botrytis cinerea*, *Fusarium* spp. and *Oidium lini*.

High Priority (HGCA/MAFF/DANI)

(iii) Evaluation of the effectiveness of different chemicals and spray-timings for the control of foliar diseases such as *Botrytis cinerea* and also for the reduction in incidence of pathogens carried on the seed.

Medium Priority (Commerce/MAFF/DANI)

4. **EPIDEMIOLOGY**

There is a paucity of information on the epidemiology of the major pathogens of linseed in the UK. It is not clear, for example, in what form *Alternaria linicola* exists during the growing season. Further R & D is required on:

the life-cycles of the major pathogens.

optimising of the level of inputs by the use of threshold values and disease forecasts.

R & D Priorities

(i) Studies of spore dispersal and disease progress on leaves, stems, capsules and seeds for *Alternaria linicola*, *Botrytis cinerea* and *Fusarium* spp.; evaluation of the importance of inoculum sources, such as seed and soil.

High Priority (HGCA/DANI/DES)

(ii) The establishment of disease-threshold values and the development of disease-forecasting systems.

Medium Priority (HGCA/MAFF)

5. INTEGRATED DISEASE MANAGEMENT

Although there is information on the effects of fungicides and choice of cultivars, only very limited data are available on the interactions between fungicides and cultivars and other inputs. Further R & D is needed on:

the formulation of an integrated approach to crop management.

R & D Priorities

(i) Studies of the interaction between various inputs - fungicides, cultivar, nitrogen, herbicides and insecticides; optimising and integration of inputs and , *eg*. use of microbial antagonists and reduced-rate fungicides.

Medium Priority (HGCA/MAFF/DANI/EC)

6. GENETICS

The breeding of linseed is in its infancy in the UK, and while much is known of the mechanisms of resistance for some pathogens, such as *Melampsora lini*, there is little information on mechanisms for the major pathogens in the UK. Further R & D is required to:

investigate sources of resistance and variation in pathogenicity.

establish the basis for disease-resistance at various growth stages.

R & D **Priorities**

(i) Study of variability in pathogens and the identification of sources of resistance and means of introduction.
Medium to High Priority (Commerce/HGCA/MAFF/SOAFD/DANI)

(ii) Study of the mechanisms of disease-resistance.
Medium Priority (HGCA/SOAFD/DANI/EC)

7. DIAGNOSTICS

The introduction of molecular and serological techniques in the field of plant breeding and disease diagnosis provides new opportunities for the study of disease-initiation and the introduction of new resistant material into linseed breeding lines. Further R & D is needed to:

investigate novel means of introducing disease-resistance.

evaluate latest disease-diagnosis techniques.

R & D **Priorities**

(i) Use of conventional and novel means to introduce disease-resistant material into linseed breeding lines.
Medium to High Priority (DANI/MAFF)

(ii) Introduction of serological and other molecular diagnosis techniques to improve the study of early stages of infection.
Medium Priority (MAFF/SOAFD/DANI)

Bearing in mind that funding is likely to be limited for a few years, it is proposed that at least some of the above recommendations could be met by a series of field experiments across the UK. The use of a number of sites would provide a range of environmental conditions and disease pressures. Disease epidemics could be manipulated by fungicide programmes. Defined disease-assesment techniques would assist considerably in the analysis of the level of disease and yield loss for major pathogens. Records of meteorological data at each site, in conjunction with details of disease levels, would be used to produce criteria to form the basis for disease-forecasting.

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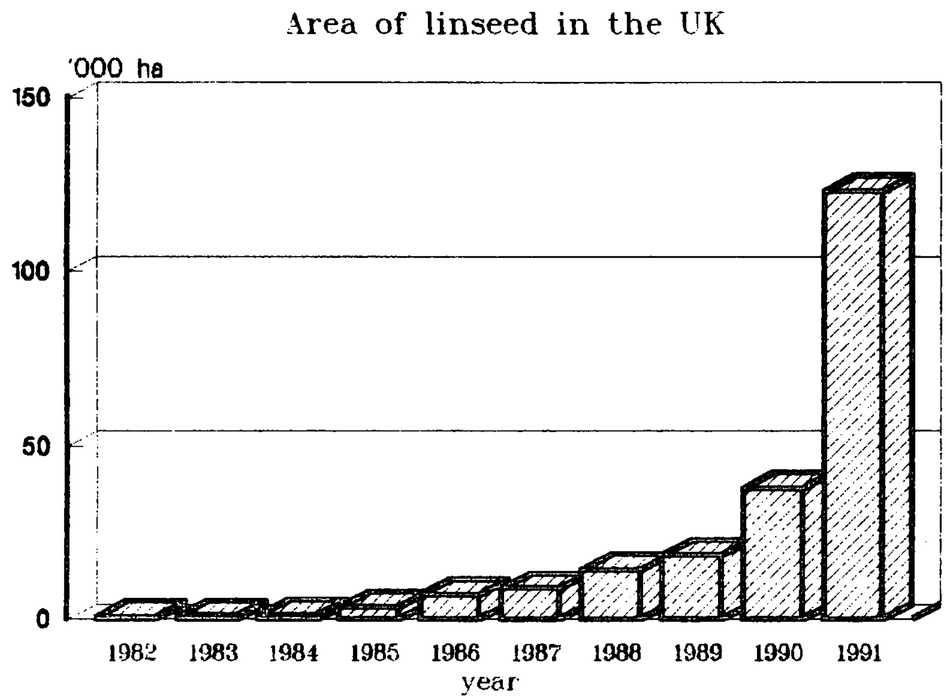
Appendix

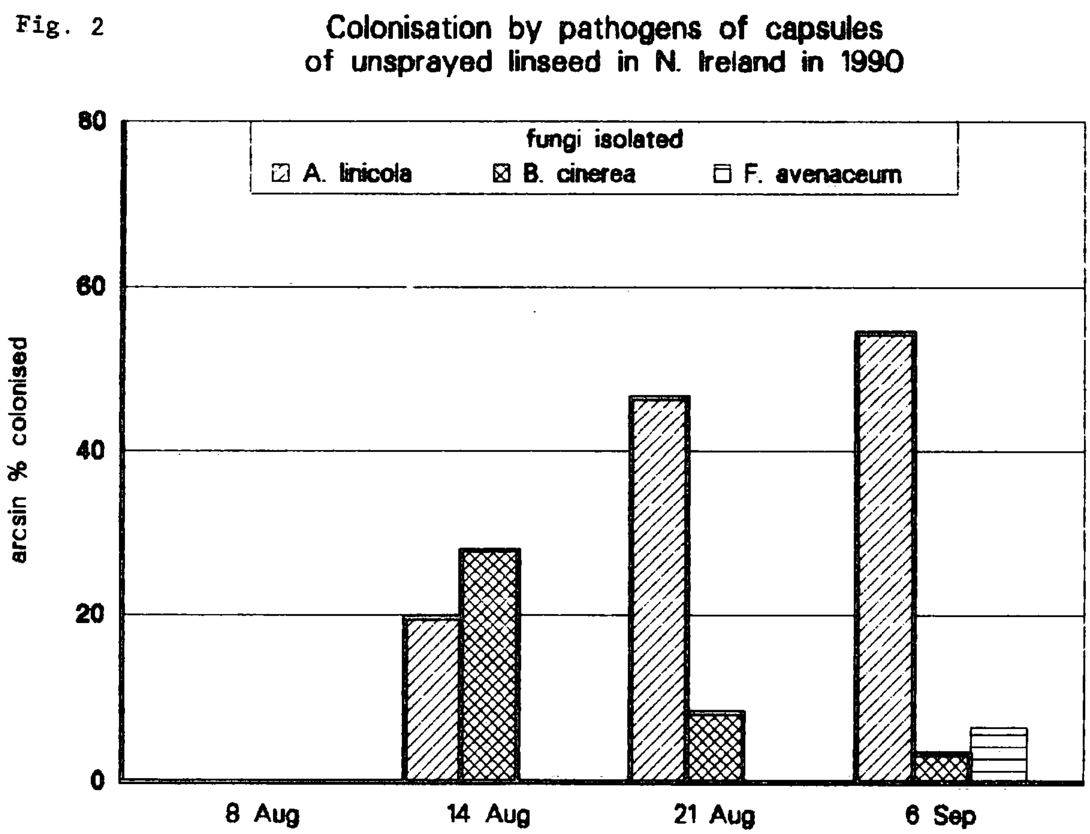
(Figures)

Fig. 1



Area of linseed in the UK
'000 ha
150
100
50
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
year

Fig. 2



Colonisation by pathogens of capsules
of unsprayed linseed in N. Ireland in 1990
fungi isolated
A. linicola
B. cinerea
F. avenaceum
arcsin % colonised
80
60
40
20
0
8 Aug
14 Aug
21 Aug
6 Sep

Fig. 3 Relative numbers of spores of Alternaria linicola trapped on sticky slides in a linseed crop in N. Ireland in 1990

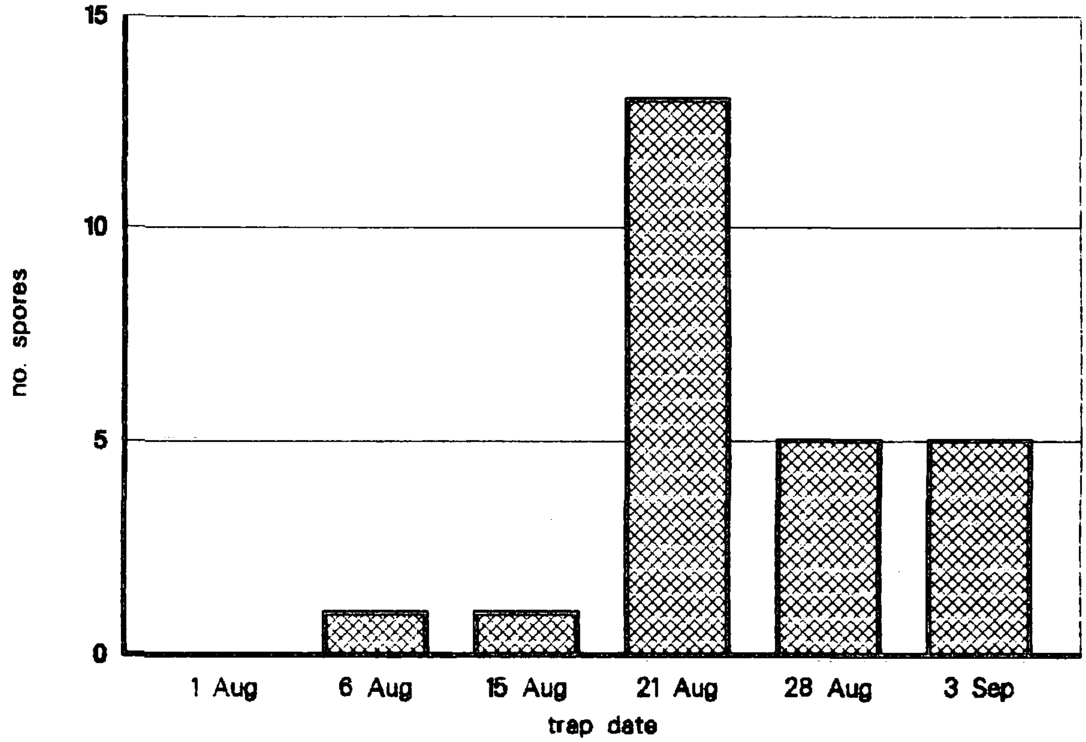


Fig. 4 Effect of age on incidence of Alternaria linicola and Botrytis cinerea on two samples of linseed seed

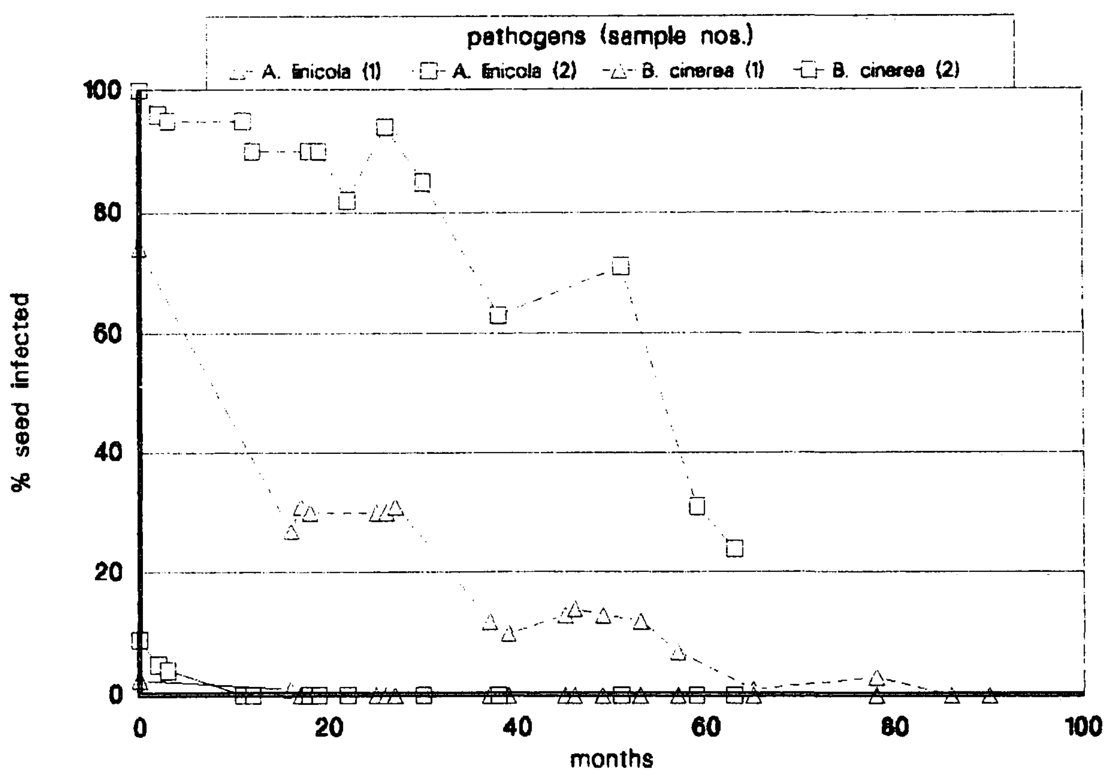


Fig. 5 Effect of age on % germination in two linseed samples

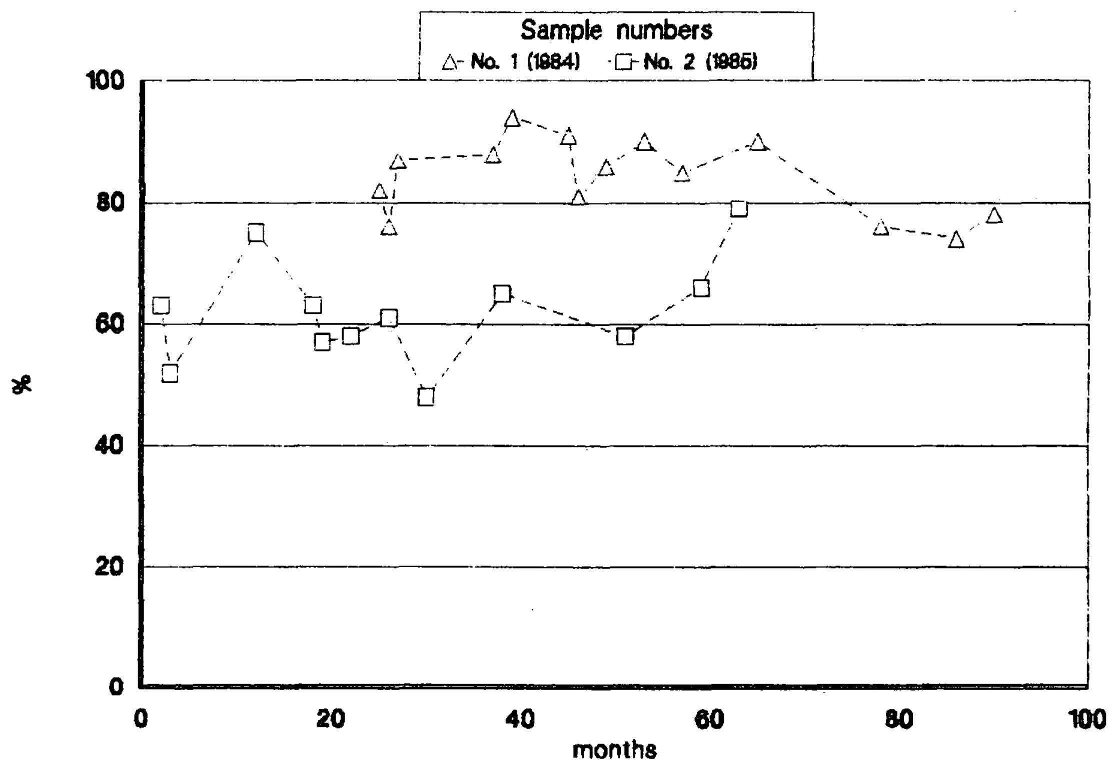
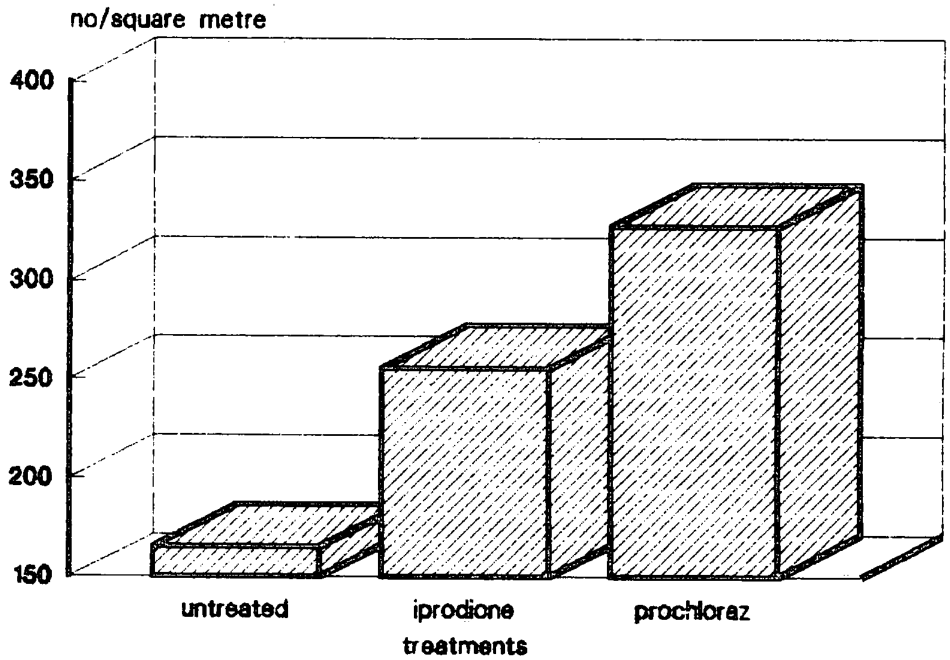


Fig. 6 Effect of seed-treatment on stand-count of linseed in N. Ireland in 1988



SE = 21.0; P < 0.001

Fig. 7 Level of resistance of Alternaria linicola to iprodione in UK linseed samples from 1986 to 1988

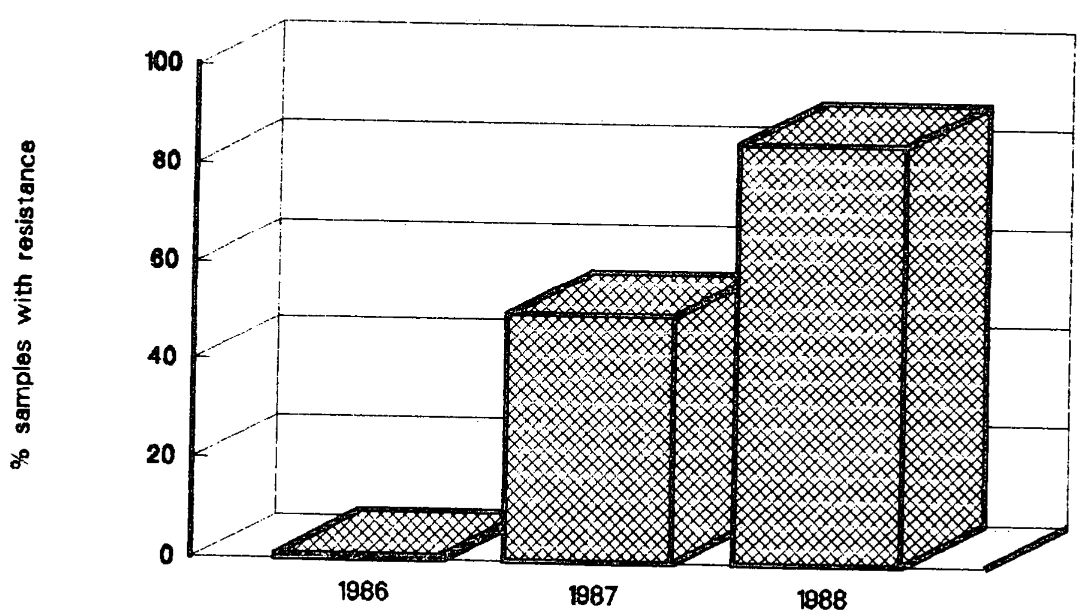


Fig. 8 Summary of seed-testing results for untreated linseed in UK in 1987

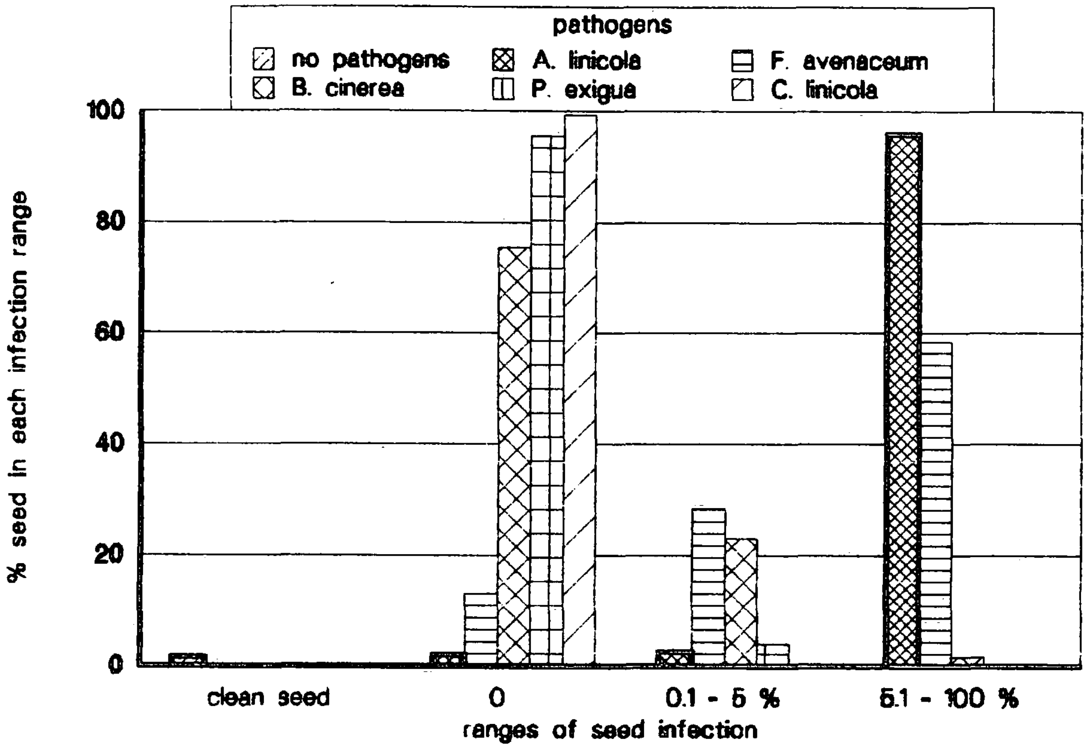
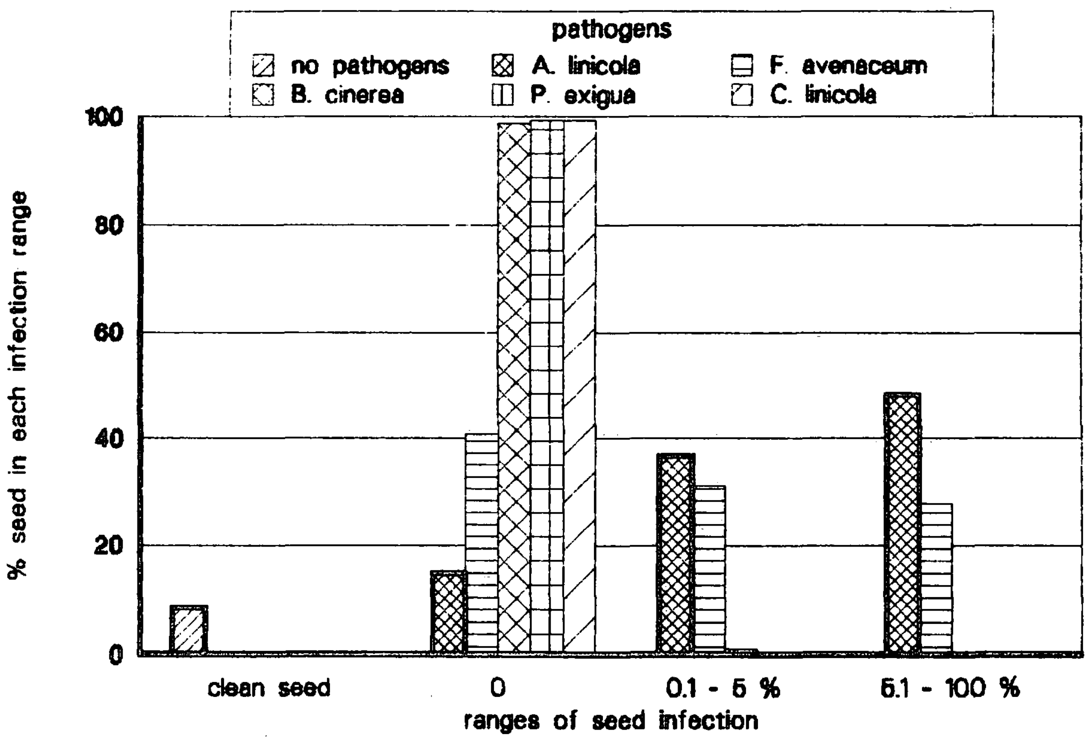


Fig. 9 Summary of seed-testing results for treated linseed in UK in 1987



total of 1567 samples; 483 untreated and 1084 treated

Fig. 10 Summary of seed-testing results for untreated linseed in UK in 1988

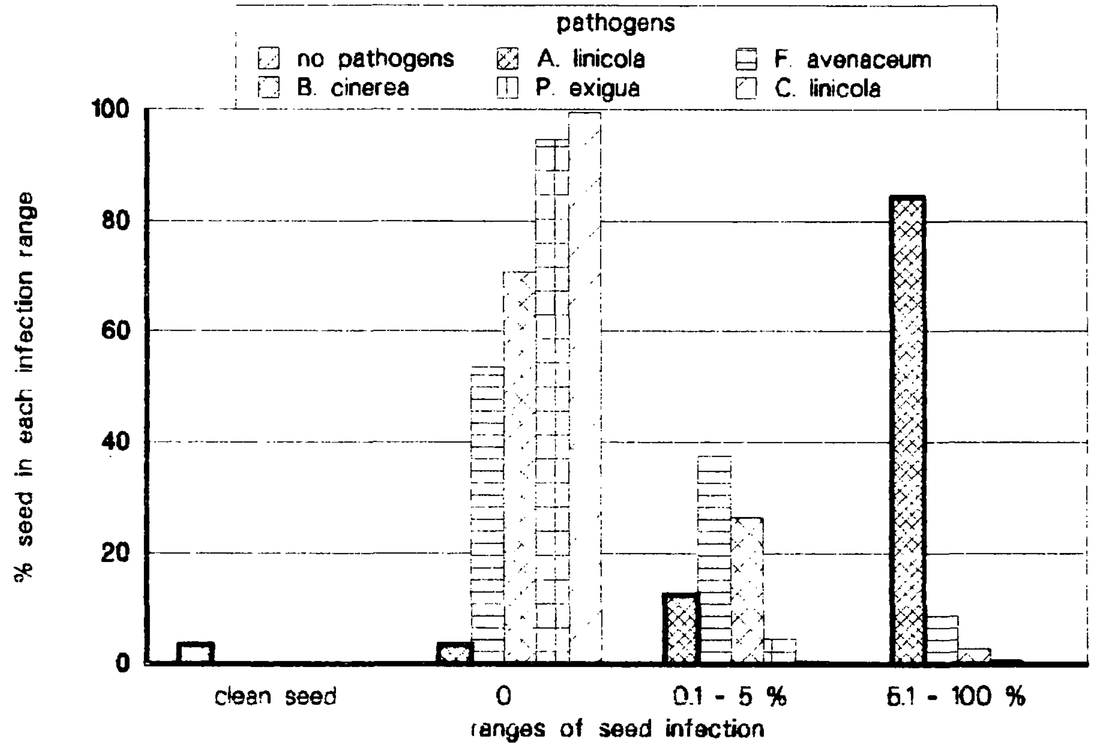
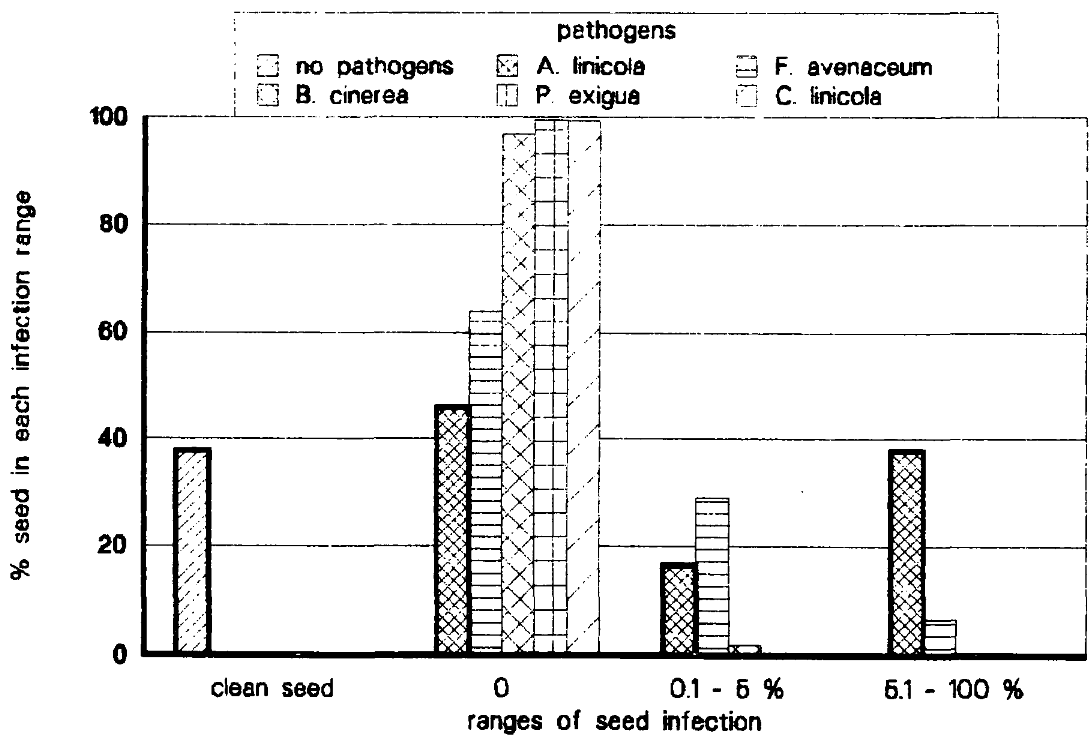


Fig. 11 Summary of seed-testing results for treated linseed in UK in 1988



total of 1058 samples; 503 untreated and 555 treated

Fig. 12 Summary of seed-testing results for untreated linseed in UK in 1989

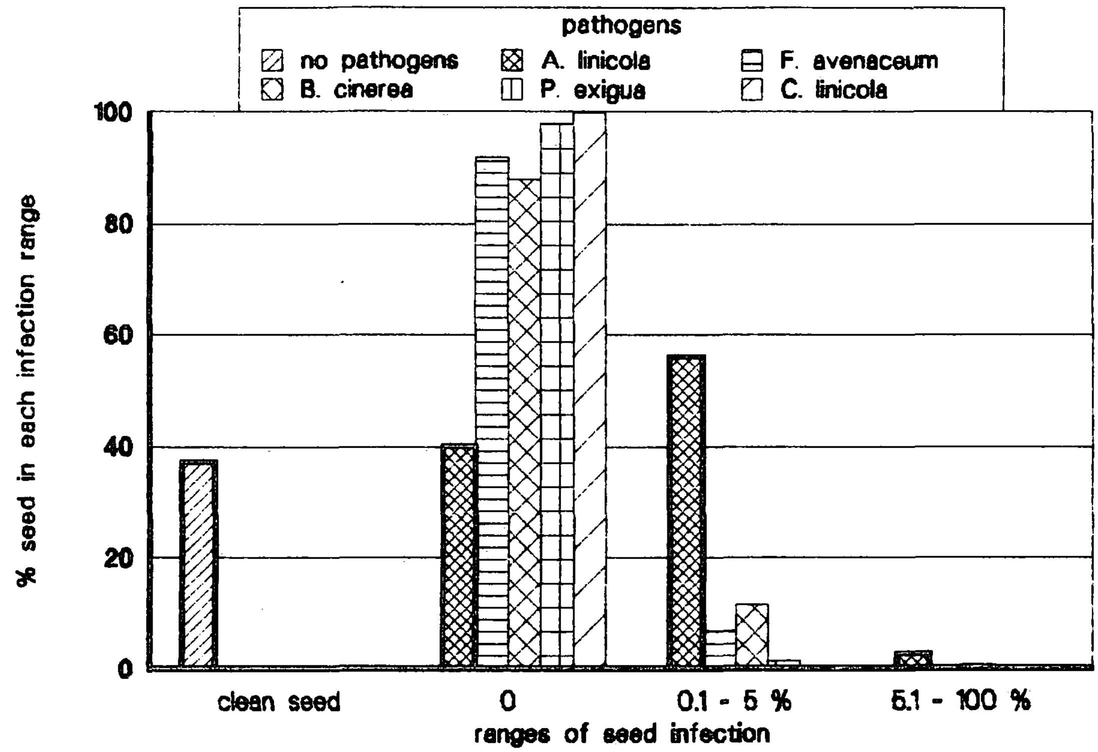
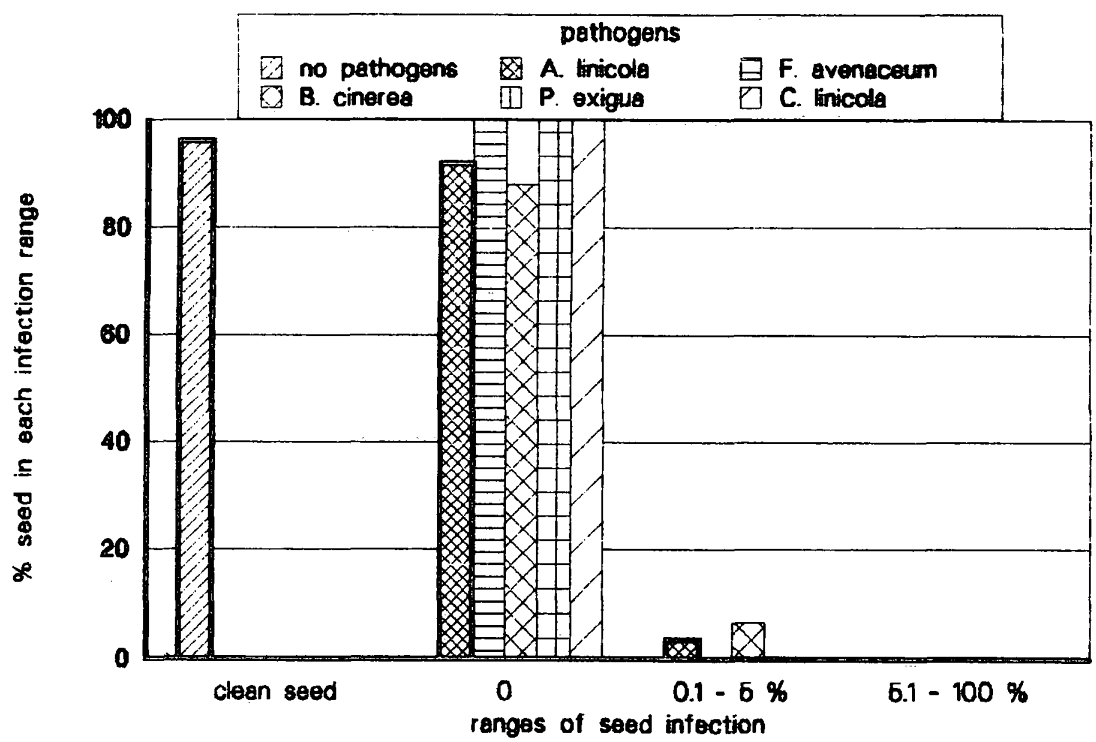


Fig. 13 Summary of seed-testing results for treated linseed in UK in 1989



total of 925 samples; 819 untreated, 106 treated

Fig. 14 Summary of seed-testing results for untreated linseed in UK in 1990

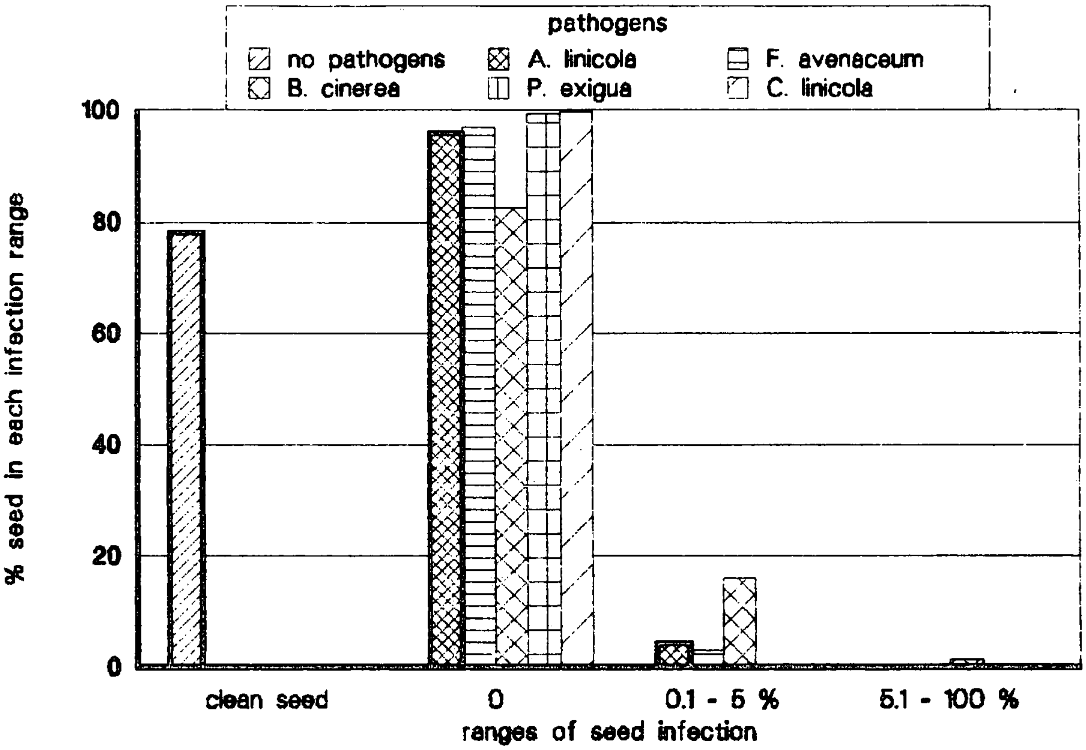
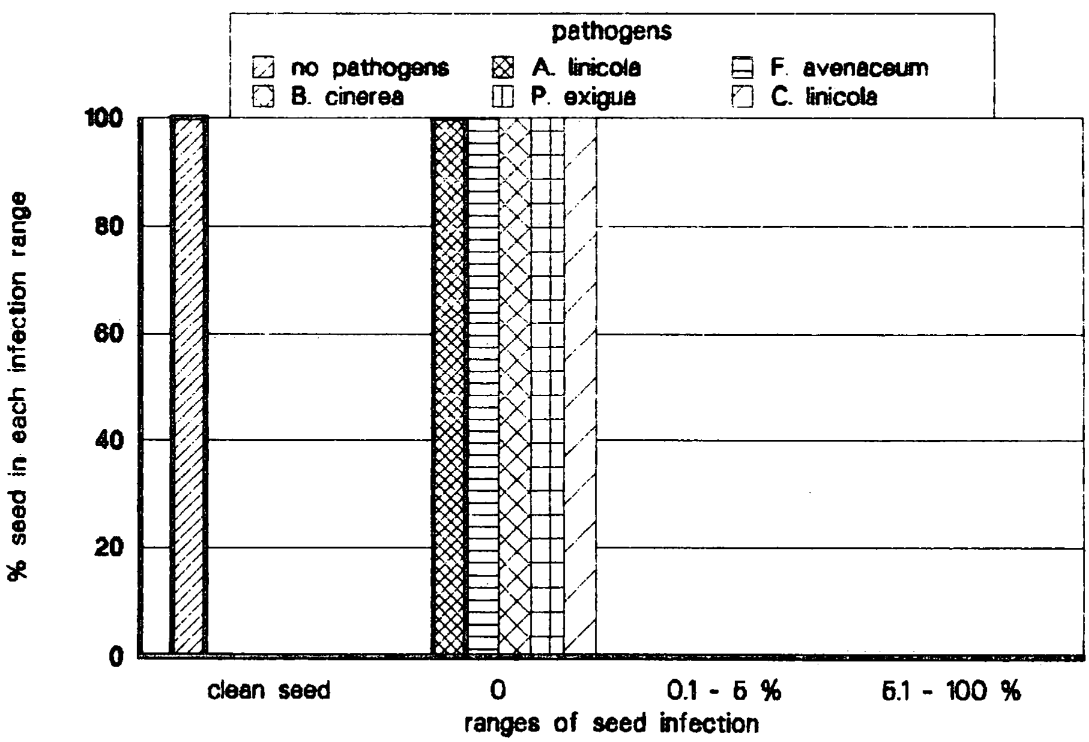


Fig. 15 Summary of seed-testing results for treated linseed in UK in 1990



total of 1109 samples; 976 untreated, 133 treated

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