Introduction
The diseases caused by fungi that affect stem bases of cereals in the UK and much of continental Europe are: eyespot, the most important of them (Figure 1), caused by Tapesia yallundae and T. acuformis; sharp eyespot, caused by Rhizoctonia cerealis; and brown (fusarium) foot rot (Figure 2) caused by Fusarium spp. and Microdochium nivale. The brown foot rot fungi also cause ear blight and can be seed-borne. M. nivale can decrease plant emergence and also cause snow mould, a serious disease of over-wintering cereals in northern latitudes. This group as a whole, therefore, has complex epidemiology that presents difficulties in control and in the choice of measures to achieve it.

Fungicides, as discussed by Leroux (1998), have been widely used for about 30 years specifically to control eyespot. Some recent reports (Burnett, 2000; Nicholson and Turner, 2000), however, have inferred from field experiments that applying fungicides, even highly active ones such as cyprodinil, has often not been cost-effective. This paper examines, by reference to recent research, the reasons for this and the prospects for the situation continuing. It also considers new research that may contribute to more cost-effective, environmentally sound disease management using an integrated approach.

Changing importance and perceived significance in the UK
Eyespot has fluctuated in importance as a target for control and, in recent years, has not always been considered by farmers as a major disease. This is despite estimates, from official surveys, that yield losses in England and Wales amounted to £16 million in 1999, the 10-year average being £17 million (N. Hardwick, personal communication). Estimated losses in 2000 were the largest for 25 years at up to £22 million at current grain prices. This confirms eyespot's significance and should not deter the development of new fungicides, research on alternative control practices or integration of eyespot control into overall disease management strategies.

Eyespot was relatively unimportant in the 1960s, mainly because of effective resistance in Cappelle-Desprez and wheat cultivars derived from it. It was maintained at low levels subsequently by fungicides, particularly the MBC group (benzimidazoles and thiophanates), and host resistance became less important. The benzimidazoles were largely replaced by other fungicides, such as prochloraz, when MBC-resistance developed in the 1980s and led to increased crop losses. Eyespot was then a research priority and much valuable epidemiological work was done (e.g. Goulds and Fitt, 1991). In many recent field trials, fungicides applied to control eyespot have often failed to increase yields significantly (Bateman et al., 2000; Burnett et al., 2000; Nicholson and Turner, 2000). The small effects on yields in many individual trials suggest that the large total losses estimated from national survey data may be mainly a consequence of modest losses in many fields rather than more variable and sometimes large losses.
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Table 1. Putative factors affecting population changes in Tapesia spp.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Suggested effect</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fungicides</td>
<td>MBCs and DMIs select for T. acuformis</td>
<td>Not proven for MBCs; good evidence for DMIs</td>
</tr>
<tr>
<td>Crop</td>
<td>Barley, rather than wheat, selects for T. acuformis</td>
<td>Good experimental evidence</td>
</tr>
<tr>
<td>Sowing date</td>
<td>Late drilling favours T. yallundae</td>
<td>Good evidence from epidemiological research</td>
</tr>
<tr>
<td>Weather</td>
<td>Various, e.g. spring frost delays T. acuformis</td>
<td>Some evidence but likely to be important only in individual crops</td>
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Sharp eyespot can cause yield losses in localised patches within crops but has never been considered a major problem. Losses in the UK have never been great (estimated in England and Wales at £4 million in 1999, with a 10-year average of £3 million, N. Hardwick, personal communication), despite the absence of effective fungicidal control. The contribution of Fusarium species to stem-base disease has long been recognised, but it came to prominence in the 1990s when research proliferated as concern about eyespot was declining. Losses are unlikely to be large. The main threat from Fusarium is ear blight, for which stem-base disease may be an important inoculum source. So far, mycotoxins that can occur in Fusarium-infected grain are at a low level in the UK but that situation could change if the climate changes.

Eyespot pathogen populations and their significance

The fast- and slow-growing pathogenic types of the eyespot fungus, formerly referred to as W-type and R-type of Pseudocercosporella herpotrichoides, have the teleomorph (sexual) stages Tapesia yallundae and T. acuformis. Fruiting bodies of T. yallundae (Figure 3) occur naturally on infested, over-wintering stubble but those of T. acuformis are rare in the field. Most epidemiological research on eyespot has concerned epidemics arising from conidia, asexual spores dispersed mostly over short distances by rain-splash. The fairly recent evidence for the production of air-borne ascospores has added a new dimension to the epidemiology of eyespot, especially as they develop readily in uncultivated set-aside fields, but their full significance has not yet been determined.

Differences in the epidemiology of the two Tapesia spp. arise mainly from their different rates of development following infection. Tapesia yallundae develops more quickly and so is often found earlier in crops (Goulds and Fitt, 1991). Weather can influence these differences: for example, it was thought that a cold winter caused loss of basal leaf sheaths that prevented further development of T. acuformis that had not yet penetrated them (Goulds and Fitt, 1991).

Both species of eyespot fungi can cause severe disease in wheat crops by the end of the growing season (Goulds and Fitt, 1991). However, the slower development of T. acuformis means that it is less likely to become severe. This was demonstrated in several field experiments but results from an experiment in which plots were inoculated with different amounts of the two fungi showed that symptoms of similar severity caused by the two pathogens were similarly damaging (Figure 4; Bateman and Jenkyn, 2000).

During the 1980s it became apparent that populations of the eyespot fungus in the UK generally changed from being predominantly the fast-growing type (T. yallundae) to predominantly the slow-growing type (T. acuformis) (King and Griffin, 1985). A recent survey suggests that T. acuformis still predominates in UK populations (West et al., 1998). It was more frequent in wheat crops in Scotland and northern England than in the south. Putative causes and significance of population changes are discussed in the following sections and are listed in Table 1.

Fungicides have undoubtedly been important in selecting Tapesia spp. MBC fungicides were implicated in the dramatic change to a predominance of T. acuformis, which occurred along with resistance to these fungicides (King and Griffin, 1985), but this was not proven experimentally (Bateman et al., 1990). Long-term experimentation suggested that this selection can occur as a result of using DMI fungicides such as prochloraz (e.g. Bateman et al., 1995). These fungicides were not used against eyespot in the early 1980s but their use against foliar diseases may possibly have affected the eyespot pathogens. Resistance to prochloraz has been found, particularly in France, but its significance there and in the UK is unclear. Repeated application to the same wheat plots at Rothamsted since 1984 has resulted in pathogen populations that are almost entirely T. acuformis because of its greater range of sensitiv-
ties (Bateman et al., 1995) but tests for resistance to prochloraz proved negative. Prochloraz-treated plots have often yielded most but the effects were never significant. This may be a consequence of the pathogen population having a large proportion, even in untreated plots, of the slower-developing T. acuformis. This suggests that the widespread use of prochloraz, whilst not always controlling eyespot, may have decreased losses and potential losses caused by eyespot by maintaining T. acuformis as the predominant fungus.

Increased barley growing was suggested as a possible contributory cause of the change to predominantly T. acuformis after 1980. It was demonstrated subsequently that barley selects for populations with greater proportions of T. acuformis than does wheat (Bateman and Gutteridge, 1996). The proportion of T. acuformis in wheat is greater in Scotland, where barley constitutes a greater proportion of the cereal acreage, than in southern England (West et al., 1998). This appears to be consistent with the experimental evidence although evidence from crop sequences sampled in the survey (West et al., 1998) was less convincing. Where a large proportion of the cereal acreage is barley, selection for T. acuformis may contribute to decreased potential losses in wheat crops.

Husbandry practices may affect the two eyespot pathogens differently because of differences in their epidemiology. Earlier sowing of winter cereals is likely to be the main factor. Greater proportions of T. acuformis were found in earlier drilled wheat crops (West et al., 1998), which allowed more time for the slow-developing R-type epidemics to become severe. The longer growing season in more northerly latitudes may also favour T. acuformis.

**Biological interactions**

It is well known that there is often an inverse relationship between eyespot and sharp eyespot and that fungicides active against eyespot can increase sharp eyespot. The strobilurin fungicide, azoxystralin, can decrease sharp eyespot if included in a stem-base treatment, but the benefit from this effect is likely to be small.

Eyespot and sharp eyespot were often more severe after ploughing than after non-inversion tillage but ploughing usually decreased fusarium foot rot (Prew et al., 1995). Straw management also affected eyespot and sharp eyespot, both of which were typically more severe where straw was burnt, despite depletion of inoculum sources, than where it was incorporated. Incorporating straw decreased these diseases only with non-inversion tillage. Brown foot rot tended to be increased by incorporating straw. However, in a year with favourable conditions for foot rot caused by F. culmorum (i.e. warm and dry in early summer), this disease was less severe after straw incorporation than after burning, despite more propagules of the fungus in the soil after straw incorporation (Bateman et al., 1998). The mechanisms are unclear and the effects are variable, although suppression by straw is easily demonstrated in glasshouse experiments (Bateman, unpublished).

**Inoculum sources and targets for control**

A severe breakout of eyespot in wheat grown after ploughing following a long period of non-inversion tillage,
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during which buried inoculum was not expected to have survived up to its return to the surface by ploughing, provided indirect evidence for the importance of ascosporic inoculum (Jenkyn and Gutteridge, unpublished). On the other hand, the continued prevalence of *T. acuminata* is known to produce ascospores commonly in the field, suggests that the widespread production of *T. yallundae* ascospores, particularly in set-aside fields, has had little general impact.

Infected straw is an important source of primary inoculum for stem-base diseases but, as indicated above, straw can also have other effects. Straw management would, therefore, seem to offer prospects for contributing to the control of these diseases. In particular, it may be possible to exploit the disease-suppressive properties of straw whilst managing it in such a way as to minimise its role as an inoculum source. Eyespot fungi are poor colonisers of straw but can survive up to 3 years when buried. *Fusarium culmorum* is a more effective straw coloniser and populations can build up very rapidly. Infected straw is therefore a less clear target for control of this fungus than for control of eyespot. Fungicides are unlikely to provide adequate control of rapidly developing brown foot rot unless they can be applied later in the season than is normal for eyespot, but only a small proportion of chemical applied at a later growth stage, using conventional spray equipment, usually reaches the stem base. Later applications would have additional, perhaps greater, value in protecting ears from inoculum originating from stem bases.

**Discussion and conclusions**

The evidence suggests that applying fungicides to control eyespot may often have small and statistically non-significant (in experiments) effects in individual fields. Widespread small effects appear sometimes to explain the relatively large estimated losses on a national basis. For the individual farmer, the economic case for controlling eyespot may often, therefore, be doubtful and a fungicide that controls leaf diseases as well as eyespot might be easier to justify. Relatively small effects on yield are likely to result from the prevalence of the pathogen *T. acuminata*, which may be being sustained by the use of DMI fungicides that are less effective against this species than against *T. yallundae*. Since the effectiveness of fungicides can not be assured, additional control measures based on husbandry, that may also be effective against other, minor, stem-base diseases, should be implemented wherever possible. Crop-debris management may be a useful component of this integrated approach but further research is needed so that the effects seen in some experiments can be exploited in a consistent and effective way. Table 2 summarises some of the current and prospective options that might be considered as components in an integrated management system for stem-base diseases.

**Acknowledgement**

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**References**


