PROJECT REPORT No. 243

DESIGNING FUNGICIDE
PROGRAMMES TO MINIMISE THE
RISK OF RESISTANCE IN WHEAT
AND BARLEY MILDEW AND WHEAT
YELLOW RUST

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DESIGNING FUNGICIDE PROGRAMMES TO MINIMISE THE RISK OF RESISTANCE IN WHEAT AND BARLEY MILDEW AND WHEAT YELLOW RUST

by

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Contents

ABSTRACT

Concerns over the development of fungicide resistance to 'new chemistry' resulted in the need:

- to establish baseline data for the sensitivity of wheat and barley powdery mildew and wheat yellow rust to the new strobilurin group of fungicides in the UK
- to detect early indications of shifts towards resistance to strobilurins
- to gather evidence on the influence of contrasting fungicide programmes on pathogen sensitivity
- to provide insight into the value of different fungicide strategies as 'anti-resistance' measures.

Wheat and barley mildew and wheat yellow rust were sampled from fungicide trials throughout the UK. Isolates were tested, on seedlings, to determine their sensitivity to morpholines, triazoles and strobilurins.

Tests confirmed that the sensitivity of wheat and barley mildew to the 'conventional' fungicides (DMIs and morpholines) has shifted towards resistance since their introduction some thirty years ago. The shift has been greater for DMIs than for morpholines and for wheat mildew than for barley mildew. There has also been a shift in the sensitivity of wheat yellow rust to DMI fungicides over the past ten years.

Resistance in wheat mildew to the new strobilurin fungicides was detected in 1999 (approx. 1% of isolates tested), following its detection the previous year in Germany. Resistance in barley mildew was not detected during the course of this project, although there have been recent reports of its appearance at a low level in the UK in 2000. There was no evidence of strobilurin resistance in wheat yellow rust. In contrast to the gradual shift towards resistance to DMIs and morpholines, strobilurin resistance developed in a single step. Resistant isolates show little or no reduction in growth on seedlings sprayed with a full dose of strobilurin.

Because of the extremely low frequency of strobilurin resistance in wheat mildew during 1998 and 1999 it was not possible to evaluate the effects of fungicide strategy on the frequency of fully resistant isolates. Despite this, there were indications that strobilurin application produced a slight quantitative shift in sensitivity.

With resistant wheat and barley mildew isolates now present in the UK, strobilurins will rapidly become less effective as mildew control agents and should not be relied upon for mildew control. There is also a risk that resistance may develop in other key pathogens. Growers should follow resistance management guidelines to reduce the risk of this occurring. More experimental evidence is needed on the effects of dose rate, number of strobilurin applications and mixture partners to ensure that resistance management strategies are effective.

SUMMARY

ABSTRACT

Recent UK studies of the resistance status of wheat and barley mildew and wheat yellow rust to DMI, morpholine and strobilurin fungicides are described. The sensitivity of both wheat and barley mildew to DMIs and morpholines has shifted significantly towards resistance compared with baseline sensitive isolates. The shift has been greater for DMIs than for morpholines and for wheat mildew than barley mildew. A small number of strobilurin-resistant isolates of wheat mildew were detected in 1999 and resistant isolates of barley mildew were reported in 2000.

INTRODUCTION

UK farmers are heavily dependent on fungicides for disease control in cereal crops. This means that any reduction in the efficacy of a fungicide due to reduced sensitivity can have serious economic consequences.

Although wheat and barley cultivars with a high degree of genetic resistance to mildew (*Erysiphe graminis*) are available to growers, fungicides still play an important role in controlling the disease in susceptible cultivars. Similarly, for yellow rust of wheat, the popularity of certain highly susceptible cultivars in recent years has contributed to epidemics and increased requirements for fungicidal control.

Morpholines and DMIs (sterol demethylation inhibitors – triazoles) have been the standards for mildew control over the past 30 years. DMIs were initially used intensively to control mildew and by the mid 1980s their performance had declined to a level at which disease control failure was commonly encountered in the field (Clark, 1992). Insensitivity to the first morpholine fungicide, ethirimol, was reported in 1979 (Walmsley-Woodward *et al*.,1979) and a shift towards insensitivity to fenpropimorph, introduced in the early 1970s, was detected in 1986 (Wolfe *et al*. 1987). Despite this, morpholines still give generally good control of mildew in the field. Control of yellow rust of wheat (*Puccinia striiformis*) on susceptible varieties is heavily dependent upon DMI fungicides, with morpholines sometimes being used for their quick eradicant effect. An investigation of yellow rust isolates collected between 1960 and 1990 gave no evidence of any changes in sensitivity to DMIs or morpholines over the period (Barnard, 1992; Bayles *et al*., 1992; Bayles *et al*., 1994).

The introduction of the strobilurin fungicides, effective against a very wide spectrum of pathogens, has created new possibilities for the control of mildews and rusts, as well as other important diseases. However, DMIs and morpholines are likely to continue as vital components of fungicide programmes, both for efficacy reasons and for considerations of resistance management. Strobilurins have a unique mode of action involving the target pathogen’s mitochondrial adenosine triphosphate (ATP) production. It was thought initially that this would be a difficult mechanism to corrupt and that the risk of resistance would therefore be low. However, strobilurin-resistant wheat mildew isolates were found in Germany in 1998 (FRAC, 1998) and more widely throughout Europe in 1999. Resistance to strobilurins in barley mildew was reported in Germany in 1999. There do not appear to be any studies of the sensitivity of yellow rust to strobilurins. Strobilurin resistance in wheat mildew arose in a single step, with full rates of the fungicide being totally ineffective against resistant isolates. This implies a single gene resistance.

Regular and independent monitoring of fungicide sensitivity in pathogen populations is essential to prevent unexpected and widespread loss of efficacy of key chemical groups. For new chemical groups, monitoring establishes a baseline sensitivity, against which future changes can be measured. Monitoring also provides essential information for evaluating anti-resistance strategies and for estimating the risk of resistance developing in a particular chemical group.

Regular and independent monitoring of fungicide sensitivity in pathogen populations is essential if unexpected and widespread loss of efficacy of key chemical groups is to be prevented by the implementation of appropriate anti-resistance management strategies (FRAG-UK, 2000; FRAC, 1998). For new chemical groups, monitoring establishes baseline sensitivity, against which future changes can be measured. Monitoring also provides essential information for evaluating anti-resistance strategies and for estimating the risk of resistance developing in particular chemical groups.

The main objectives of this project were firstly to establish baseline data for the sensitivity of wheat and barley powdery mildew and wheat yellow rust to the new strobilurin group of fungicides and secondly to gather evidence on the influence of contrasting fungicide regimes on pathogen sensitivity. This approach was designed to detect early evidence of shifts towards resistance and provide insight into the value of different fungicide strategies as ‘anti-resistance’ measures.

MATERIALS AND METHODS

Mildew

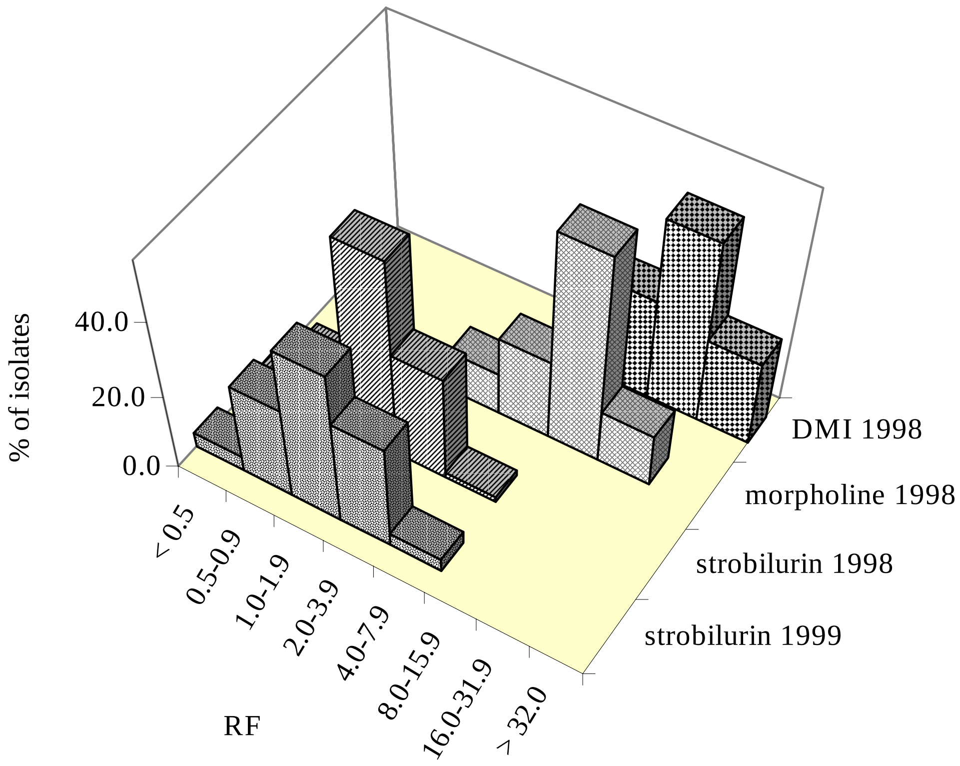
Wheat and barley mildew samples were taken from fungicide trials at 12 sites in the UK in 1998 and at 15 sites in 1999. Samples were collected from plots receiving a range of different fungicide programmes, including conventional chemistry alone and various combinations of conventional and strobilurin chemistry. In 1998, all samples were collected after the final spray of each programme. In 1999, additional samples were collected before the start of spraying and, in some trials, part way through the spray programme.

Mildew isolates were maintained in the laboratory on universally susceptible cultivars of wheat and barley, either using seedlings growing in isolation propagators or detached leaf segments on agar in plastic boxes.

A total of 450 isolates of wheat mildew and 245 isolates of barley mildew were tested for fungicide sensitivity using detached leaf assays. Isolates were tested using established methods for sensitivity monitoring studies (Burnett, 1999; S. Slater, pers. comm.). Seedlings of the susceptible cultivar were sprayed with a range of fungicide concentrations and an untreated control was sprayed with water. Leaf segments cut from the sprayed seedlings were placed on agar containing 80-100 ppm benzimidazole and inoculated evenly with spores of each test isolate. At least two sensitive control isolates were included in each test. After approximately 14 days incubation, the surface area of the leaf segments infected by mildew was assessed. From this, EC_{50} values were estimated for each isolate. Resistance factors (RF) were calculated as the EC_{50} of a test isolate divided by the mean EC_{50} of the sensitive control isolates. In 1998, isolates were tested for sensitivity to DMIs (using epoxiconazole or tebuconazole), morpholines (using fenpropimorph) and strobilurins (using azoxystrobin). In 1999, isolates were tested for sensitivity to strobilurins only.

Yellow rust

Samples of wheat yellow rust were collected from fungicide trials in 1998 and 1999. 33 isolates were tested for sensitivity to the strobilurin fungicide azoxystrobin, using a seedling test method based on that of Barnard (1992) described by Bayles (1998) was used. EC_{50} values were estimated and a resistance factor calculated for each isolate compared with two control isolates (Barnard, 1992), collected in surveys before the deployment of strobilurin fungicides.



RESULTS

Figure 1 shows the distribution of resistance factors (RF) for the sensitivity of barley mildew isolates to DMI and morpholine fungicides in 1998 and to strobilurins in 1998 and 1999. A RF value of 1.0 represents the sensitivity of the sensitive baseline control isolates. The distribution of RFs for DMIs was further towards insensitivity than that for morpholines, with nearly 70 percent of isolates having RF values greater than 16 for DMIs compared with around 15 percent for morpholines. RF values for sensitivity to strobilurins occupied a narrow range on either side of the control isolates, with maximum values in the 4.0-7.9 group. Distributions in 1998 and 1999 were almost identical.

Figure 2 shows RF distributions for the sensitivity of wheat mildew isolates to DMI and morpholine fungicides in 1998 and to strobilurins in 1998 and 1999. It also shows the distribution of RF values for the sensitivity of yellow rust isolates to strobilurins, for the two years together. As with barley mildew, the distribution of RFs for DMIs was further towards insensitivity than the distribution for morpholines. For strobilurin sensitivity there was a narrow distribution of low RF values in 1998, similar to that found in barley mildew. However, in 1999, three strobilurin-resistant isolates were detected, resulting in a discontinuous distribution of RFs. These isolates were fully resistant, showing very little reduction in growth at rates of azoxystrobin equivalent to twice the full dose. It was therefore impossible to calculate true EC_{50}s or RFs. The distribution of RF values for the sensitivity of wheat yellow rust isolates to strobilurins was similar to that for wheat mildew in 1998 and barley mildew in both years.

Figure 1. Distributions of RF values for barley mildew isolates

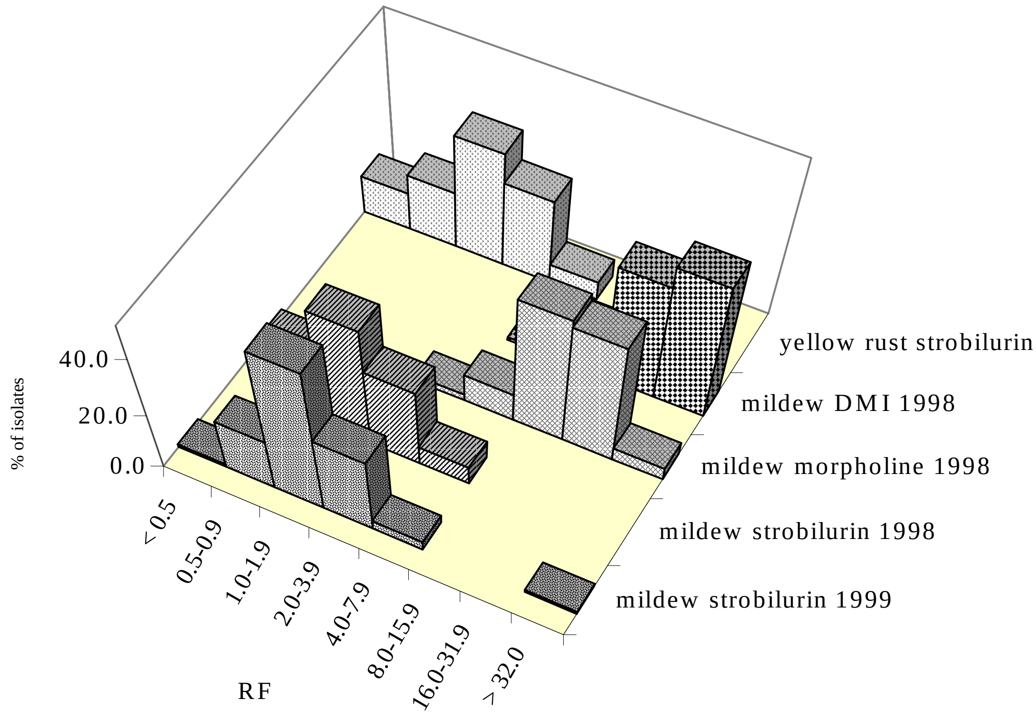


Figure 2. Distributions of RF values for wheat mildew and yellow rust isolates

DISCUSSION

These studies provide an update on the current resistance status of wheat mildew, barley mildew and wheat yellow rust with respect to key fungicide groups in the UK. The sensitivity of both wheat and barley mildew to DMIs and morpholines has clearly shifted since fungicides in these groups were introduced some thirty years ago. This is hardly surprising considering the continuous widespread use of this chemistry over a long period and the intrinsically high resistance risk of the pathogens concerned. The shift towards resistance has been greater for DMIs than for morpholines and for wheat mildew than for barley mildew. Average resistance factors for wheat mildew isolates in 1998/1999 were 31.8 for DMIs and 16.7 for morpholines, indicating a 32-fold or 17-fold increase in the dose of fungicide required to reduce the growth of the pathogen by 50%, when compared with unselected baseline isolates. Comparable resistance factors for barley mildew were 23.5 for DMIs and 10.7 for morpholines. Further monitoring would be needed to determine whether the sensitivity of these pathogens has stabilised or is continuing to decline. With the advent of new chemical groups with activity against mildew, there would seem to be the opportunity to stabilise the position of the older chemistry by use of mixtures and alternations of fungicides with different modes of action.

When the strobilurin sensitivity monitoring described here started, it was widely believed that the risk of resistance to this new chemistry was low. Whether resistance, if it did develop, would do so as a gradual shift or in a single large step, was unknown. However, in the first year of monitoring, 1998, resistance to strobilurins was reported in wheat mildew in Germany and it became clear that resistance is controlled by a major gene and occurs as a single step, resulting in two distinct populations of mildew, i.e. sensitive and resistant. The following year, 1999, this UK project detected resistance in wheat mildew in isolates collected in East Anglia. This was confirmed by monitoring results released by the agrochemical industry's Fungicide Resistance Action Committee (FRAC), a specialist group of the Global Crop Protection Federation (GCPF) dedicated to prolonging the effectiveness of fungicides liable to encounter resistance problems. Resistant isolates show little or no reduction in growth on seedlings sprayed with azoxystrobin at full dose rate. Judging by the rate at which resistance in wheat mildew appeared throughout Europe, it seems likely that the incidence of resistance in the UK will increase to high levels within one or two years, rendering strobilurins totally ineffective in controlling mildew. There is clearly a high risk that barley mildew will follow the same course. Isolates of barley powdery mildew resistant to strobilurins have since been identified, by Syngenta, in the north of Scotland (S. Heaney, BCPC 2000 presentation).

An important objective of these investigations was to gather evidence on the influence of different fungicide strategies on pathogen sensitivity to strobilurins and the value of these strategies as 'anti-resistance' measures. However, during the period of the project, resistance was at only a very low frequency in the wheat mildew population and was undetectable in the barley mildew population. This made it impossible to measure effects of fungicide strategy on the frequency of fully resistant isolates. Despite this, there was some evidence that strobilurin application may produce a slight quantitative shift in sensitivity. The average RF of wheat mildew isolates sampled from plots that had received at least one strobilurin spray had, on average, slightly higher RF. Barley mildew isolates showed a similar, although non-significant, trend.

Mixed spray programmes utilising fungicides with different modes of action are only valuable as anti-resistance strategies if there is no cross resistance between the fungicides concerned and if combined resistance is uncommon. There was no evidence here of cross resistance between DMIs, morpholines and strobilurins. However, it appears that the general shift in the mildew populations towards reduced sensitivity to both the DMIs and morpholines has resulted in a significant proportion of isolates showing reduced sensitivity to both these chemicals i.e. combined resistance.

Over the last ten years there has been a clear shift in the sensitivity of wheat yellow rust population towards insensitivity to DMI fungicides (B. Napier *et al*., 2000) in the wheat yellow rust population. A combination of cultivar susceptibility and weather conditions, together with a tendency for fungicides to be used at rates well below those recommended, resulted in widespread yellow rust infection and inadequate control. In response to the high disease risk, DMIs were used repeatedly in many crops, starting with seed dressings and followed by foliar applications. On theoretical grounds, prolonged exposure to a fungicide is generally believed to increase selection for insensitivity and may well have contributed to the shift observed.

Although there have been no confirmed cases of insensitivity causing failure of yellow rust control in the field, it is clearly important that every effort should be made to halt the sensitivity shift. Appropriate anti-resistance measures include growing resistant varieties, following the principles of variety diversification and spraying at the first signs of infection using adequate dose rates. Repeated applications of DMIs alone should be avoided by using co-formulations, recommended tank-mixes or sequences of sprays which bring together different modes of action effective against yellow rust (FRAG-UK, 2000).

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SCIENTIFIC REPORT

INTRODUCTION

UK farmers are heavily dependent on fungicides for disease control in cereal crops. This means that any reduction in the efficacy of a fungicide due to reduced sensitivity can have serious economic consequences.

Although wheat and barley cultivars with a high degree of genetic resistance to mildew (*Erysiphe graminis*) are available to growers, fungicides still play an important role in controlling the disease in susceptible cultivars. Similarly, for yellow rust (*Puccinia striiformis*) of wheat, the popularity of certain highly susceptible cultivars in recent years has contributed to epidemics and increased requirements for fungicidal control. When a fungicide is working at full efficacy the target pathogen is considered to be sensitive. Mutations in the pathogen can result in a decrease in the sensitivity or resistance, dependent upon the genes involved. If a single gene of the pathogen is responsible for sensitivity then a single step mutation can result in resistance to a fungicide arising in a single step, resulting in two groups of the fungus – one resistant and the other sensitive with no overlap between the groups (Georgopoulos and Skylakakis, 1986). Alternatively, if many mutated genes are required to produce resistant isolates then these genes will appear in combinations with various ratios of unmutated genes resulting in a continuous distribution in the measured sensitivity within the population. This type of resistance is termed polygenic resistance (Georgopoulos, 1987).

There are three main groups of fungicides used for mildew control in the UK the reductase / isomerase inhibitors (morpholines, spiroketalamine), DMIs (sterol demethylation inhibitors) and strobilurins. The changes, in sensitivity of the first two groups, have been tracked extensively. Morpholines and DMIs have been the standards for mildew control over the past thirty years. DMIs were initially used intensively to control mildew and by the mid 1980s their performance had declined to a level at which disease control failure was commonly encountered in the field (Clark, 1992). Mutations in the mildew population have resulted in polygenic resistance towards DMIs with reduced uptake of the fungicide by the target pathogen (Klepser *et al*., 1997). Insensitivity to the first morpholine fungicide, ethirimol, was reported in 1979 (Walmsley-Woodward *et al*., 1979) and a shift towards insensitivity to fenpropimorph, introduced in the early 1970s, was detected in 1986 (Wolfe *et al*., 1987). Despite this, morpholines still give generally good control of mildew in the field. Control of yellow rust of wheat (*Puccinia striiformis*) on susceptible varieties is heavily dependent upon DMI fungicides, with morpholines sometimes being used for their quick eradicant effect. An investigation of yellow rust isolates collected between 1960 and 1990 gave no evidence of any changes in sensitivity to DMIs or morpholines over the period (Barnard, 1992; Bayles *et al*., 1992; Bayles *et* *al*., 1994). A more recent survey (Bayles, 1998) has shown a significant shift towards insensitivity since the 1960 – 1990 survey.

The introduction of the strobilurin fungicides, effective against a very wide spectrum of pathogens, offered new possibilities for the control of mildews and rusts, as well as other important diseases. However, DMIs and morpholines remained as vital components of fungicide programmes, both for efficacy reasons and for considerations of resistance management. Strobilurins have a unique mode of action involving the target pathogen's mitochondrial adenosine triphosphate (ATP) production. It was thought initially that this would be a difficult mechanism to corrupt and that the risk of resistance would therefore be low. However, strobilurin-resistant wheat mildew isolates were found in Germany in 1998 (FRAC, 1998) and more widely throughout Europe in 1999. Resistance to strobilurins in barley mildew was reported in Germany in 1999. There do not appear to be any studies of the sensitivity of yellow rust to strobilurins. Strobilurin resistance in wheat mildew arose in a single step, with full rates of the fungicide being totally ineffective against resistant isolates. This implies a single gene resistance.

Regular and independent monitoring of fungicide sensitivity in pathogen populations is essential if unexpected and widespread loss of efficacy of key chemical groups is to be prevented by the implementation of appropriate anti-resistance management strategies (FRAG-UK, 2000; FRAC, 1998). For new chemical groups, monitoring establishes baseline sensitivity, against which future changes can be measured. Monitoring also provides essential information for evaluating anti-resistance strategies and for estimating the risk of resistance developing in particular chemical groups.

The main objectives of this project were firstly to establish baseline data for the sensitivity of wheat and barley powdery mildew and wheat yellow rust to the new strobilurin group of fungicides and secondly to gather evidence on the influence of contrasting fungicide regimes on pathogen sensitivity. This approach was designed to detect early evidence of shifts towards resistance and provide insight into the value of different fungicide strategies as 'anti-resistance' measures.

MATERIALS AND METHODS

Mildew

NIAB

Wheat and barley mildew samples were taken from fungicide trials at ten sites in England and Wales in 1998 and at ten sites in 1999. Samples were collected from plots receiving a range of different fungicide programmes, including conventional chemistry alone and various combinations of conventional and strobilurin chemistry (Appendix 1). In 1998, all samples were collected three to four weeks after the final spray of each programme. The timing of the sampling was to allow growth of isolates capable of surviving on the sprayed plants. Leaves were sampled from five points along the length of the plot. The samples were maintained as populations on detached leaf segments, of universally susceptible cultivars, on 100 ppm benzimidazole agar in plastic boxes or using seedlings growing in isolation propagators. Wheat mildew isolates were sampled from the cultivar Claire and maintained on the universally susceptible cultivar Cerco, whilst barley isolates were collected from the cultivar Fanfare and maintained on the universally susceptible cultivar Golden Promise. In 1999, additional samples were collected before the start of spraying and, in some trials, part way through the spray programme. The treatments selected included untreated (sampled prior to GS 31 to prevent re-infection from treated plots) and strobilurin treatments. In addition to sampling leaves from trials, trays of seedlings, sprayed with ¼ rate azoxystrobin, were put out to act as spore traps. Trap plants were used on three occasions in Cambridgeshire and Suffolk. Claire was the cultivar sampled for the wheat mildew; Hanna, Fanfare and Regina for the winter barley; Delibes, Prisma and Optic for the spring barley.

Isolates were tested using established methods for sensitivity monitoring studies (S. Slater, pers. comm.). Seedlings of the susceptible cultivar were sprayed with a range of fungicide concentrations (Table 1) and an untreated control was sprayed with water. Leaf segments cut from the sprayed seedlings were placed on agar containing 100 ppm benzimidazole and inoculated evenly with spores of each test isolate. At least two sensitive control isolates, from those listed in Table 2, were included in each test. After ten days incubation, the surface area of the leaf segments infected by mildew was assessed. From this, EC_{50} values were estimated for each isolate. Resistance factors (RF) were calculated as the EC_{50} of a test isolate divided by the mean EC_{50} of the sensitive control isolates. In 1998, isolates were tested for sensitivity to DMIs (epoxiconazole), morpholines (fenpropimorph) and strobilurins (using azoxystrobin and kresoxim-methyl). In 1999, isolates were tested for sensitivity to strobilurins (azoxystrobin) only. Both laboratories used very similar methods for testing sensitivity and shared control isolates so that RFs were directly comparable.

Isolates from the NIAB culture collection that were considered insensitive were also included as controls but were not included in the calculation of RF values in 1998. In 1999 the morpholine and DMI insensitive isolates were used as controls as they are strobilurin sensitive.

Table 1. Fungicide rates (NAIB)

Treatment	Year	Rate
Untreated (water)	1998 + 1999	
fenpropimorph	1998	@ 8, 32, 64, 128, 256 and 512 ppm
azoxystrobin	1998	@ 8, 32, 64, 128, 256 and 512 ppm
kresoxim-methyl	1998	@ 8, 32, 64, 128, 256 and 512 ppm
epoxiconazole	1998	@ 8, 32, 64, 128, 256 and 512 ppm
azoxystrobin	1999	@ 8, 32, 64, 256, 512 and 1024 ppm
fenpropimorph	1999	@ 8, 32, 64, 256, 512 and 1024 ppm
epoxiconazole	1999	@ 8, 32, 64, 256, 512 and 1024 ppm

Table 2. Mildew control isolates (NIAB).

Isolate	Sensitivity	Status	Crop	History
CC/1	morpholine & DMI sensitive	Control	Barley	1970
CC/2	morpholine & DMI sensitive	Control	Barley	1972
CC/212	strobilurin sensitive	Control	Barley	1991
CC/234	strobilurin sensitive	Control	Barley	1993
B/ATH/39	morpholine & DMI sensitive	Control	Barley	pre 1996
WC/3	morpholine & DMI sensitive	Control	Wheat	1972
WC/10	morpholine & DMI sensitive	Control	Wheat	1978
W95/307/B	morpholine & DMI sensitive	Control	Wheat	1995
W94/71/3	strobilurin sensitive	Control	Wheat	1994
W96/183/1	strobilurin sensitive	Control	Wheat	1996
98DE1211R*	strobilurin resistant	Control	Wheat	1998

*A strobilurin resistant wheat mildew isolate was imported from Germany under a PHSI licence to act as a control for any resistant isolates.

Fungicides were applied using a field application simulation sprayer, delivering at a rate of 220 l/ha at a pressure of 2 bar. 24 hours after being sprayed a single 30 mm leaf segment was cut from the first leaf of each plant. The leaf segments were placed in pairs on benzimidazole agar in 35 x 25 mm plastic boxes. After a further 24 hours each mildew isolate was inoculated onto four boxes of every treatment. To ensure even coverage of all the leaves a settling tower was used. This is a 900 mm high, 300 mm diameter steel tube into which the spores were blown through a 20 mm hole in the side 110 mm from the top of the tower. The top of the tower was sealed with a metal plate and the boxes were placed at the bottom, which was also sealed. The inoculated leaves were incubated for 10 days at 16 °C with 12 hour photoperiod. Finally the leaves were assessed on a 0 – 10 scale where 0 is no growth and 10 is full coverage of the leaf by mildew pustules. Using the sum of the values from the eight leaf segments of each dose and chemical EC_{50} values were estimated for each chemical.

<u>SAC</u>

Wheat and barley mildew samples were intensively sampled from two fungicide trials in 1998 and sampled from nine sites in 1999. Samples were collected from plots receiving a range of different fungicide programmes, including conventional chemistry alone and various combinations of conventional and strobilurin chemistry (Appendix 2). There were also treatments that involved different dose rates and numbers of applications. In 1998, samples were collected before the first spray and two weeks after subsequent spray applications if mildew was still visible in the plots. The timing of the sampling was to allow growth of isolates capable of surviving on the sprayed plants. Leaves were sampled from the centre of each plot. Ten to fifteen leaves were sampled from the same leaf layer within each trial. Isolates were transported back to the laboratory in a lightly inflated plastic bag, in an insulated cool box. If mildew pustules were sparse at sampling then the samples were maintained as populations on detached leaf segments, of universally susceptible cultivars, on 80 ppm benzimidazole agar in petri dishes until there was enough inoculum to transfer onto whole plant seedlings. If pustules were numerous populations were transferred onto seedlings of the universally susceptible cultivars growing in isolation propagators. Wheat mildew isolates were maintained on Cerco, whilst barley isolates were maintained on Golden Promise.

In 1998 wheat mildew isolates were sampled from Riband and barley isolates from Prisma. In the following year isolates were sampled from the cultivars Regina, Delibes, Muscat, Riband, Prisma, Consort and Optic.

Isolates were tested using established methods for sensitivity monitoring studies (Robertson et al. (1990), Zziwa (1999)). Seedlings of the susceptible cultivar were sprayed with a range of fungicide concentrations and an untreated control was sprayed with water. Leaf segments cut from the sprayed seedlings were placed on agar containing 80 ppm benzimidazole and inoculated evenly with spores of each test isolate. At least two sensitive control isolates were included in each test. After approximately 14 days incubation, the surface area of the leaf segments infected by mildew was assessed. From this, EC_{50} values were estimated for each isolate. Resistance factors (RF) were calculated as the EC_{50} of a test isolate divided by the mean

EC_{50} of the sensitive control isolates. In 1998, isolates were tested for sensitivity to DMIs (using epoxiconazole or tebuconazole), morpholines (fenpropimorph) and strobilurins (using azoxystrobin and kresoxim-methyl). In 1999, isolates were tested for sensitivity to strobilurins (azoxystrobin) only.

Table 3. Mildew control isolates (SAC)

Isolate name	Sensitivity	Crop
CC1	morpholine sensitive DMI sensitive	Barley
ATH 39	morpholine sensitive, DMI resistant	Barley
AB95/B	morpholine resistant, triazole resistant	Barley
WC/3	DMI sensitive, morpholine sensitive	Wheat
AB/96/A	DMI sensitive, morpholine sensitive	Wheat
96/183/1	DMI sensitive, morpholine resistant	Wheat
R156	morpholine resistant DMI resistant	Wheat
95/307/B	morpholine resistant DMI resistant	Wheat
ATH/94/B	morpholine sensitive, DMI resistant	Wheat

Maintenance of mildew isolates

The wheat cultivar used to maintain isolates and to carry out the tests was ‘Cerco’ which carries no known resistance genes to powdery mildew. The barley isolates were maintained on the universally susceptible cultivar ‘Golden Promise’. The isolates were maintained on these cultivars on isolation propagators, using whole plants so that sufficient inoculum could be multiplied up for the tests. For the multiplication of inoculum around twenty seedlings were used per pot. The isolation propagator uses 12.5 cm pots covered in clear Perspex covers and operates by blowing a continuous stream of air up through the centre of each pot and cover to avoid contamination from airborne inoculum and cross contamination from other mildew isolates. Plants are watered from a reservoir underneath through wicks.

Mildew isolates were sub-cultured twice, taking six weeks, on whole plants on the isolation propagator to generate sufficient inoculum (22 pots inoculum required per isolate).

Testing of isolates

To carry out the tests, wheat seedlings were grown as above with around ten plants per pot. Test plants were grown on an isolation propagator until GS 13 - 14. These were then transferred to a dedicated spray cabinet and sprayed with the test fungicides using a Humbrol spray gun for ten seconds. The compounds and dose rates used are listed in Tables 4 and 5.

Control plants were sprayed with water. Each spray treatment was replicated using the same spray cabinet. Treated sets of plants were kept apart for 24 hours before the preparation of leaf segments. To carry out the tests sixteen segments (2 cm long) were cut from the second true leaf of the treated plants from each concentration and spray cabinet combination and then plated, eight per petri dish, on Davis minimal medium containing 80 mg l^{-1} benzimidazole and inoculated with the experimental isolates. Inoculation was carried out by transferring the mildew inoculum from the heavily infected plants used for maintenance and distributing this evenly over the surface of the leaf segment using a fine, sterile paint brush. The inoculum used was 14 days old. Dishes were placed in an 18°C incubator and kept in a 12 hour photoperiod.

After 14 days the surface area of the leaf segments affected was assessed and recorded. This was then analysed using a Genstat 5 programme that calculated the median percentage mildew cover and fitted symmetrical logistic curves to the data. From this EC_{50} values can be estimated. The EC_{50} is estimated from the dose-response curve as the median effective concentration of the pesticide which produces half the maximum effect on the isolate (Brown, 1991). This gives a measure of how sensitive isolates are to the pesticide, a low value representing a sensitive isolate and a high value representing a resistant or insensitive isolate. Resistance factors (RF) were calculated as the EC_{50} of a test isolate divided by the mean EC_{50} of the sensitive control isolates.

Table 4. Test chemicals and dose rates used in wheat tests (SAC).

Active ingredient	Product	g a.i./ha	Amount of full commercial dose rate applied.
1) azoxystrobin	Amistar	250	1/32, 1/16,1/8, 1/4, 1/2, 1.0, 5.0 of normal dose
2) kresoxim-methyl	test substance*	105	1/32, 1/16,1/8, 1/4 of normal dose
3) fenpropidin	Patrol	750	1/64, 1/32, 1/16,1/8 of normal dose
4) fenpropimorph	Corbel	750	1/64, 1/32, 1/16, 1/8 of normal dose
5) tebuconazole	Folicur	105	1/32, 1/16,1/8, 1/4 of normal dose
6) epoxiconazole	Opus	125	1/32, 1/16,1/8, 1/4 of normal dose
7) Water control			

Table 5. Test chemicals and dose rates used in barley tests (SAC).

Active ingredient	Product	g a.i./ha	Amount of full commercial dose rate applied.
1) azoxystrobin	Amistar	250	1/32, 1/16,1/8, 1/4, 1/2, 1.0 of normal dose
2) kresoxim-methyl	test substance*	105	1/32, 1/16,1/8, 1/4 of normal dose
3) fenpropidin	Patrol	750	1/32, 1/16,1/8, 1/4 of normal dose
4) fenpropimorph	Corbel	750	1/32, 1/16,1/8, 1/4 of normal dose
5) tebuconazole	Folicur	105	1/32, 1/16,1/8, 1/4 of normal dose
6) epoxiconazole	Opus	125	1/32, 1/16,1/8, 1/4 of normal dose
7) Water control			

*Kresoxim-methyl is formulated for use in cereals in a mix with fenpropimorph as the product Ensign (kresoxim-methyl, 150g/l, plus fenpropimorph, 300 g/l). It was applied here as straight kresoxim-methyl at an equivalent rate to the full commercial dose in Ensign.

A strobilurin resistant wheat mildew isolate was imported from Germany under a Scottish Office licence to act as a control for any resistant isolates.

Glasshouse experiments into dose and application number

In order to test the influence of dose rate and application number on the development of resistance in a mixed population of resistant and sensitive wheat mildew isolates a series of glasshouse experiments was carried out. Inoculum for three sensitive control isolates and the one strobilurin resistant isolate were grown separately on whole seedlings on the isolation propagator until there was sufficient inoculum for the first experiment. The inoculum was then bulked by weight so that the bulked inoculum at the start of the experiments was made up of 10% resistant isolate and 90% sensitive isolates. A resistant control and a sensitive control were included in the experiment.

Cerco seedlings were sown for the experiments and grown on an isolation propagator. At GS 14 weaker seedling were picked out to leave ten healthy seedlings per pot. Plants were then sprayed with Amistar at the dose rates shown in table 6, using the methodology described for sensitivity testing above. There were three replicates of each treatment. Plants were left for 24 hours with the treatments separated to reduce the influence of any vapour movement between treatments. Plants were then inoculated using a spore settling tower. After inoculation plant were left on the isolation propagator for 14 days. The inoculum on each pot was transferred onto fresh Cerco seedlings, on the isolation propagator, to bulk enough inoculum for sensitivity testing and for further inoculations, for second and third applications of the same dose rate of Amistar. For some of the treatments this took three cycles of bulking.

Table 6. Treatments applied, as a series of three applications, in glasshouse experiments.

	Treatment	
Mixed population	Water control	Amistar @1/32, 1/8, 1/4, 1/2 dose rate
Sensitive control	Water control	Amistar @1/32, 1/8, 1/4, 1/2 dose rate
Resistant control	Water control	Amistar @1/32, 1/8, 1/4, 1/2 dose rate

Each replicate of each treatment was then tested for sensitivity to azoxystrobin using the methodology described above.

Yellow rust of wheat

Samples of wheat yellow rust were collected from fungicide trials in 1998 and 1999. Thirty-three isolates were tested for sensitivity to the strobilurin fungicide azoxystrobin, using a seedling test method based on that of Barnard (1992). The yellow rust was multiplied on the universally susceptible cultivar Vuka and the spores freeze-dried and stored in ampoules. EC_{50} values were estimated and a resistance factor calculated for each isolate compared with two control isolates, collected in surveys before the deployment of strobilurin fungicides.

Table 7. Yellow rust control isolates.

Isolate	Sensitivity	Status	History
83/62	Strobilurin sensitive	Control	1983
90/20	Strobilurin sensitive	Control	1990

The yellow rust was only tested for insensitivity to azoxystrobin at 0, 1, 2, 4 and 8 ppm. Seedlings of Vuka were sprayed as with the NIAB mildew testing. Again the plants were left 24 hours before being inoculated, as whole plants. The inoculated plants were then incubated for 48 hours at 7 °C. The plants were grown for a further 12 days at 18 °C with a 16 hour photoperiod. EC_{50} values were calculated.

RESULTS

A total of 450 isolates of wheat mildew and 245 isolates of barley mildew were tested for fungicide sensitivity using detached leaf assays (Appendix 3 and 4).

1998 was a year of low mildew incidence in England and Wales. This, combined with the fact that the majority of the plots sampled had received robust spray programmes, led to few viable samples. At each NIAB site samples were bulked by treatment for testing. The Scottish trials chosen for sampling in 1998 had early mildew infections and higher than average levels of infection. Scottish isolates were tested separately from each replicate treatment plot.

The 1998 testing showed a broad range of RFs for the DMIs and morpholines but only a narrow range of values for the strobilurins.

1999 was also a year of below average incidence of mildew although early sampling of the untreated plots and multiple sampling of the treated plots resulted in a larger number of viable isolates. Three strobilurin resistant wheat mildew isolates were found and were tested for sensitivity to fenpropimorph and epoxiconazole. These three isolates were also tested to determine their virulence factors (Table 8) using differential varieties (Clarkson and Slater 2000). These three isolates were potentially virulent on cultivars grown on more than half of the area of winter wheat grown in 2000.

Table 8. Virulence factors of strobilurin resistant wheat mildew isolates

Isolate	Virulence
RR99/47	V2,4,5,6,8,9,Tal,(17?), Ss^,Aa,Sham
RR99/166	V2,4,5,6,8,Tal,(Ss^?)
RR99/184	V2,3b,4,5,6,8,Tal,(17?)Ss^

Figure 1 shows the distribution of resistance factors (RF) for the sensitivity of barley mildew isolates to DMI and morpholine fungicides in 1998 and to strobilurins in 1998 and 1999. A RF value of 1.0 represents the sensitivity of the sensitive baseline control isolates. The distribution of RFs for DMIs was further towards insensitivity than that for morpholines, with nearly 70 percent of isolates having RF values greater than 16 for DMIs compared with around 15 percent for morpholines. RF values for sensitivity to strobilurins occupied a narrow range on either side of the control isolates, with maximum values in the 4.0-7.9 group. Distributions in 1998 and 1999 were almost identical.

Figures 2 and 4 show the relationships between RF values for DMI and morpholine sensitivity for barley and wheat mildew. The cross hairs represent the median value for each of the fungicides. The lack of correlation within the two scatter diagrams (barley r = 0.028; wheat r = 0.087) confirms an absence of cross resistance between DMIs and morpholines. Some isolates have combined resistance but this is by chance rather than any link between modes of action.

Figure 3 shows RF distributions for the sensitivity of wheat mildew isolates to DMI and morpholine fungicides in 1998 and to strobilurins in 1998 and 1999. As with barley mildew, the distribution of RFs for DMIs was further towards insensitivity than the distribution for morpholines. For strobilurin sensitivity there was a narrow distribution of low RF values in 1998, similar to that found in barley mildew. However, in 1999, three strobilurin-resistant isolates were detected, resulting in a discontinuous distribution of RFs. These isolates were fully resistant, showing very little reduction in growth at rates of azoxystrobin equivalent to twice the full dose. It was therefore impossible to calculate true EC_{50}s or RFs. The distribution of RF values for the sensitivity of wheat yellow rust isolates to strobilurins was similar to that for wheat mildew in 1998 and barley mildew in both years.

Figure 5 shows the distribution of RF values for the sensitivity of yellow rust isolates to strobilurins, for the two years together. The distribution is similar to that of the sensitive mildew populations.

Table 9 shows the RFs for the 3 strobilurin resistant wheat mildew isolates compared with 3 strobilurin sensitive controls. The sensitivity of the strobilurin resistant isolates to morpholines and DMIs fell within the bounds of the wheat mildew population, as judged by the 1998 data.

Figure 6 shows mean strobilurin RFs for isolates collected from plots receiving, or not receiving, a strobilurin application. The three fully resistant isolates have been omitted. The wheat mildew data has been split into one and two strobilurin applications.

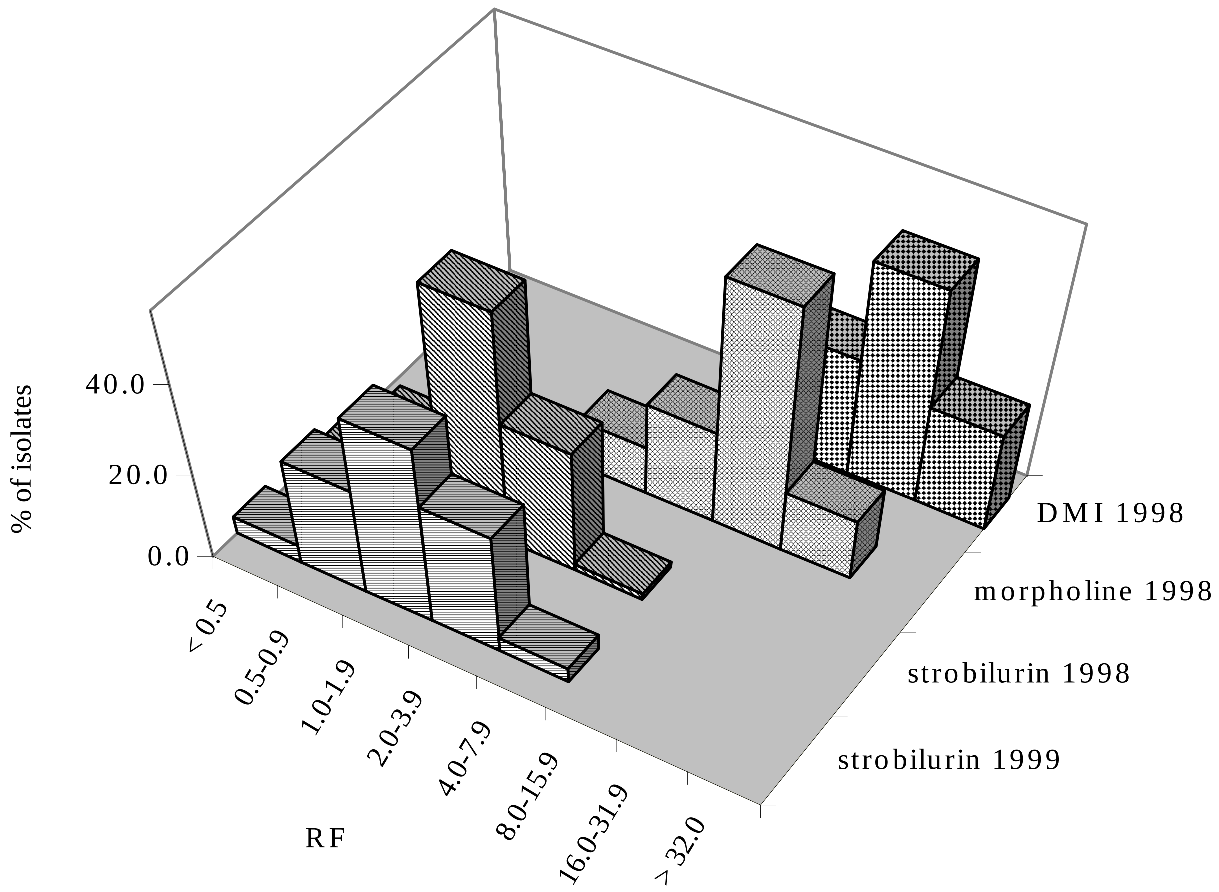
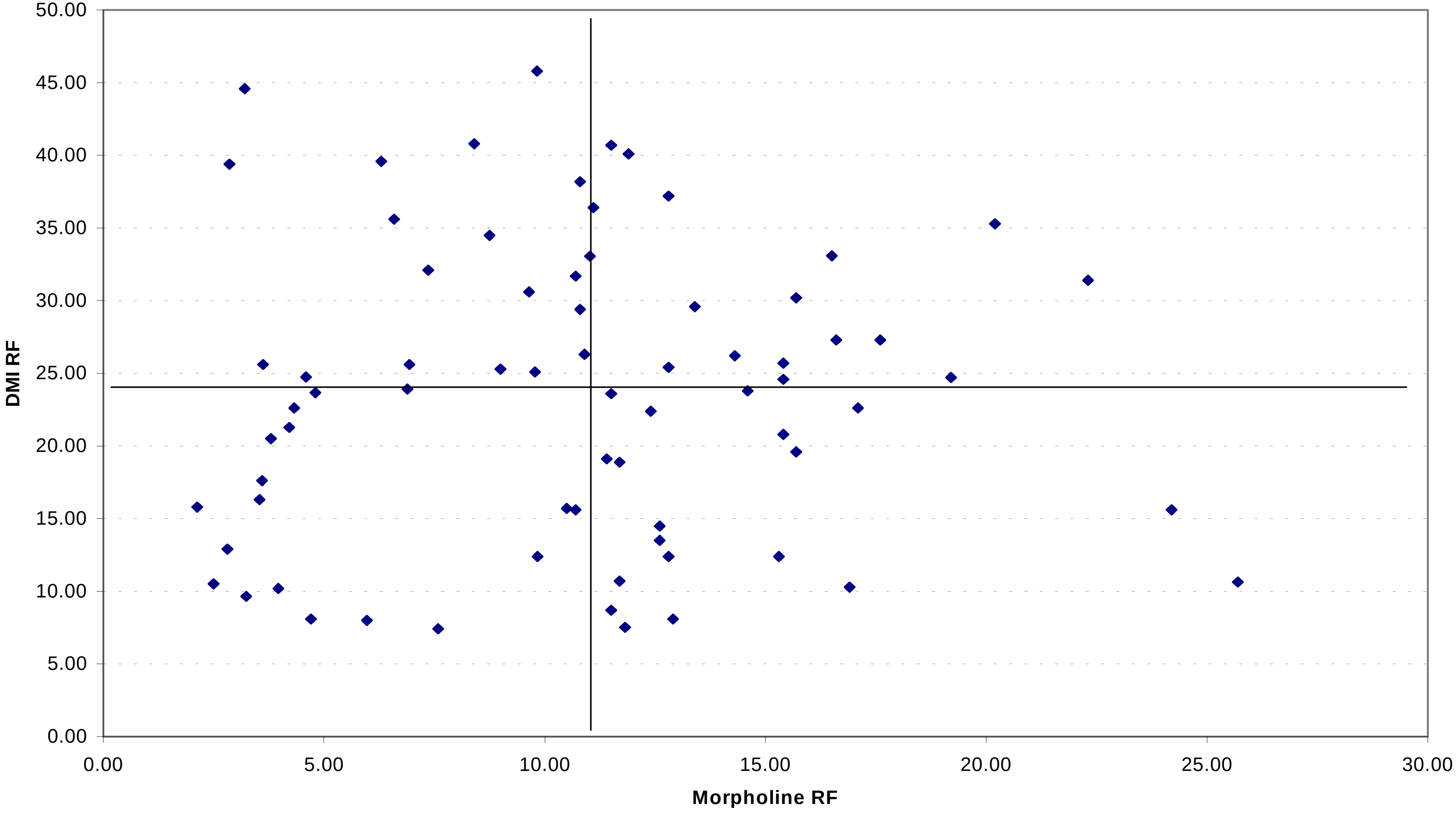


Figure 1. Distributions of RF values for barley mildew isolates.



correlation coefficient = 0.028

Figure 2. Scatter diagram of Morpholine and DMI RF values of the barley mildew isolates.

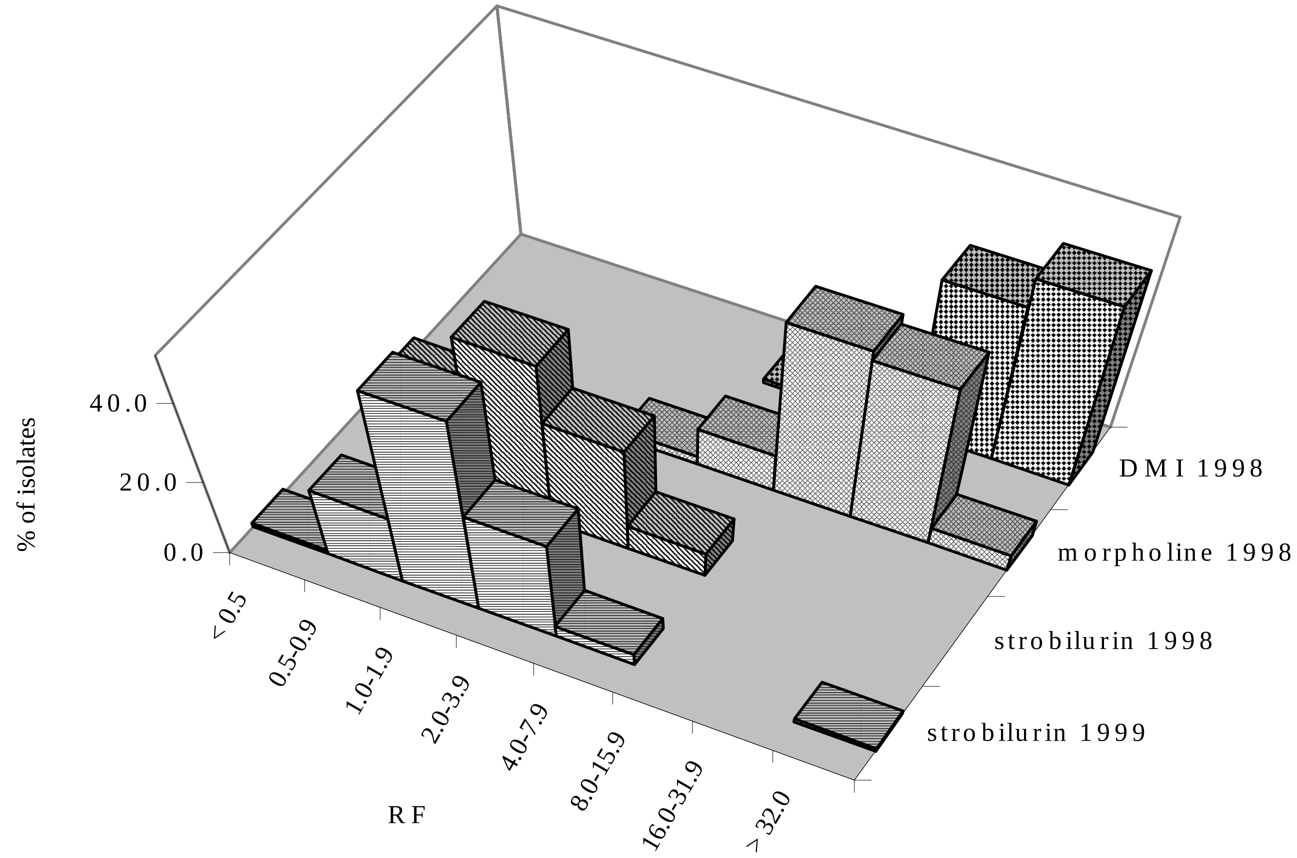
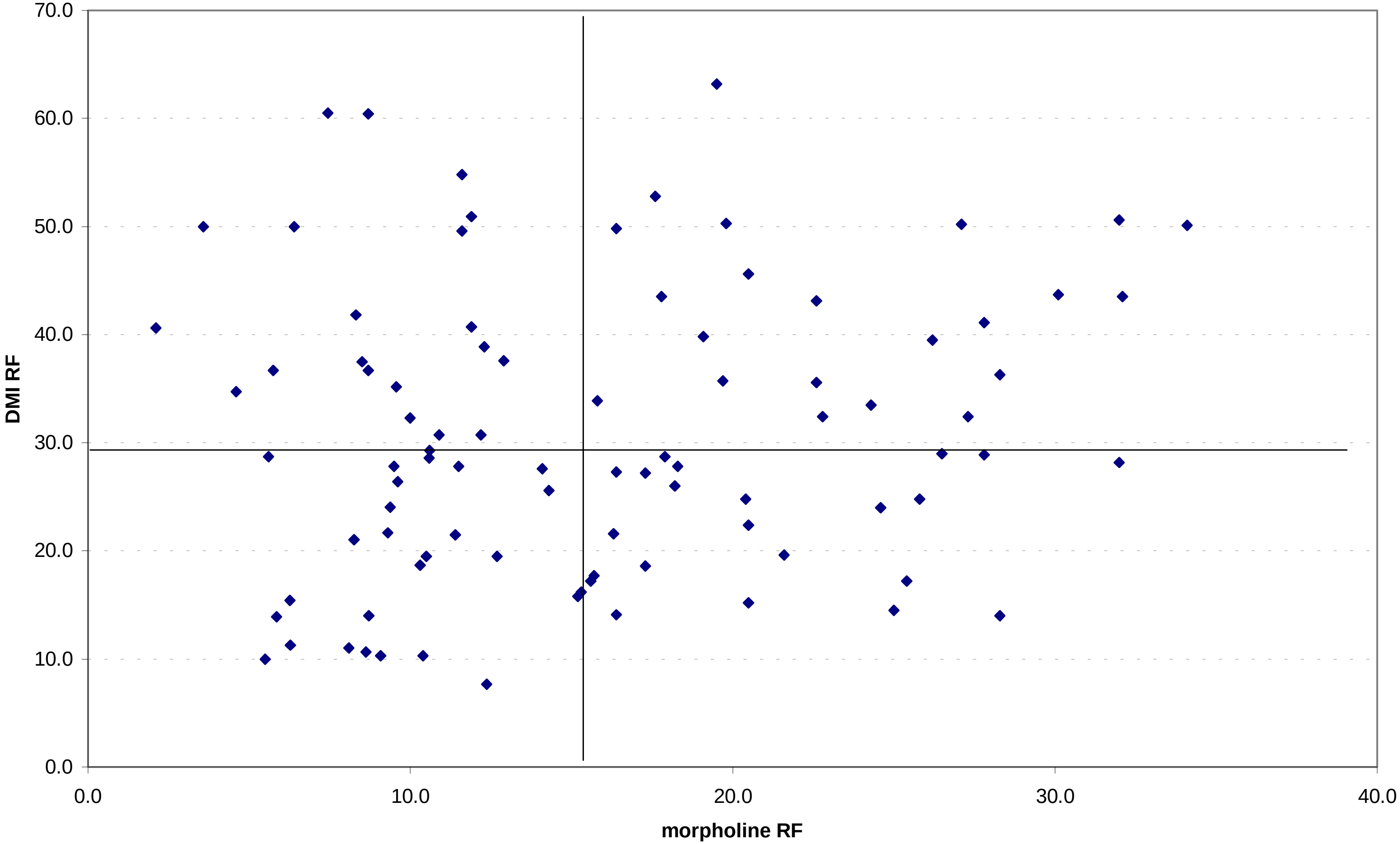


Figure 3. Distributions of RF values for wheat mildew isolates



Correlation coefficient = 0.087

Figure 4. Scatter diagram of Morpholine and DMI RF values of the wheat mildew isolates.

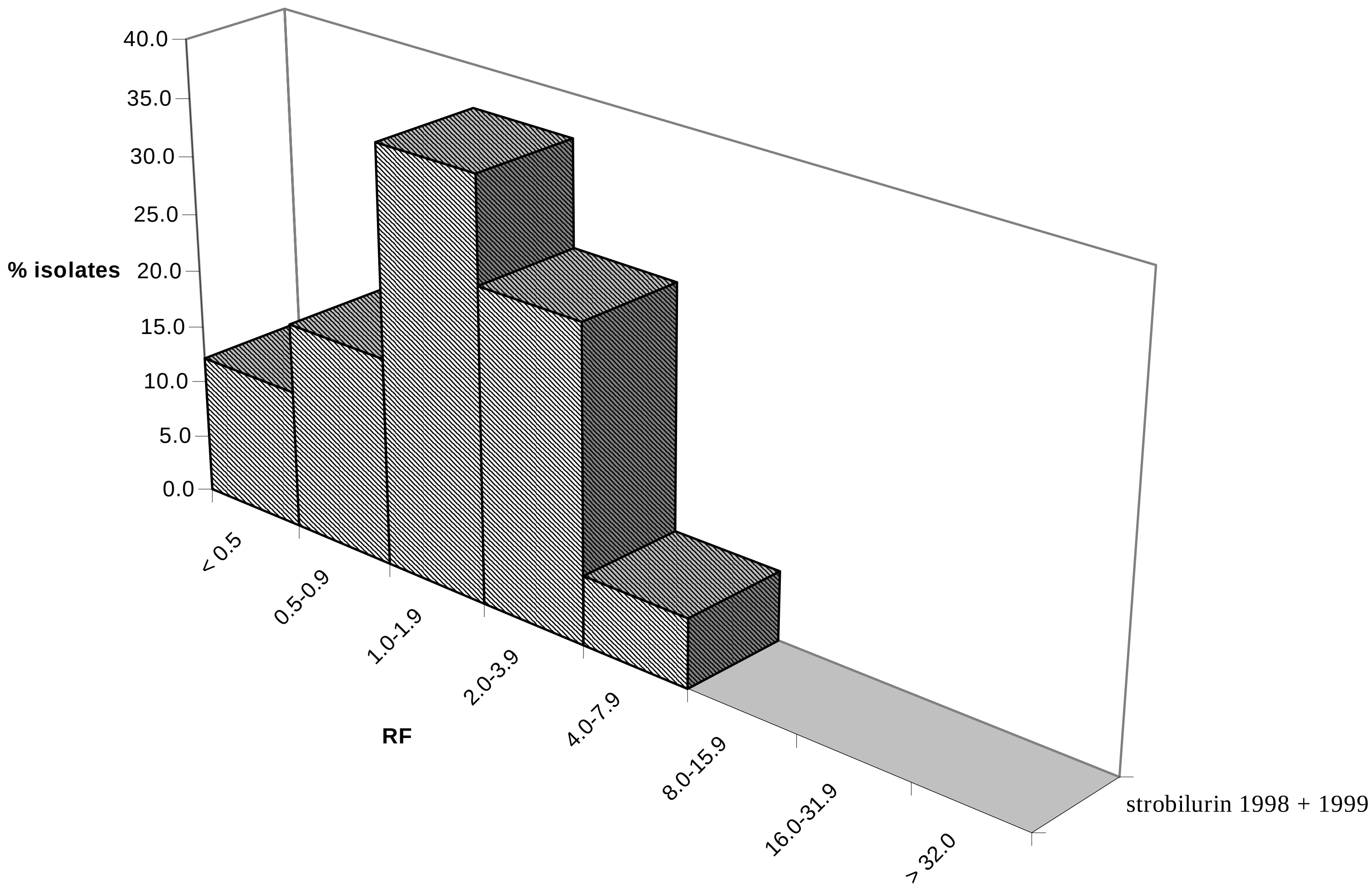


Figure 5. Distributions of RF values for wheat yellow rust isolates.

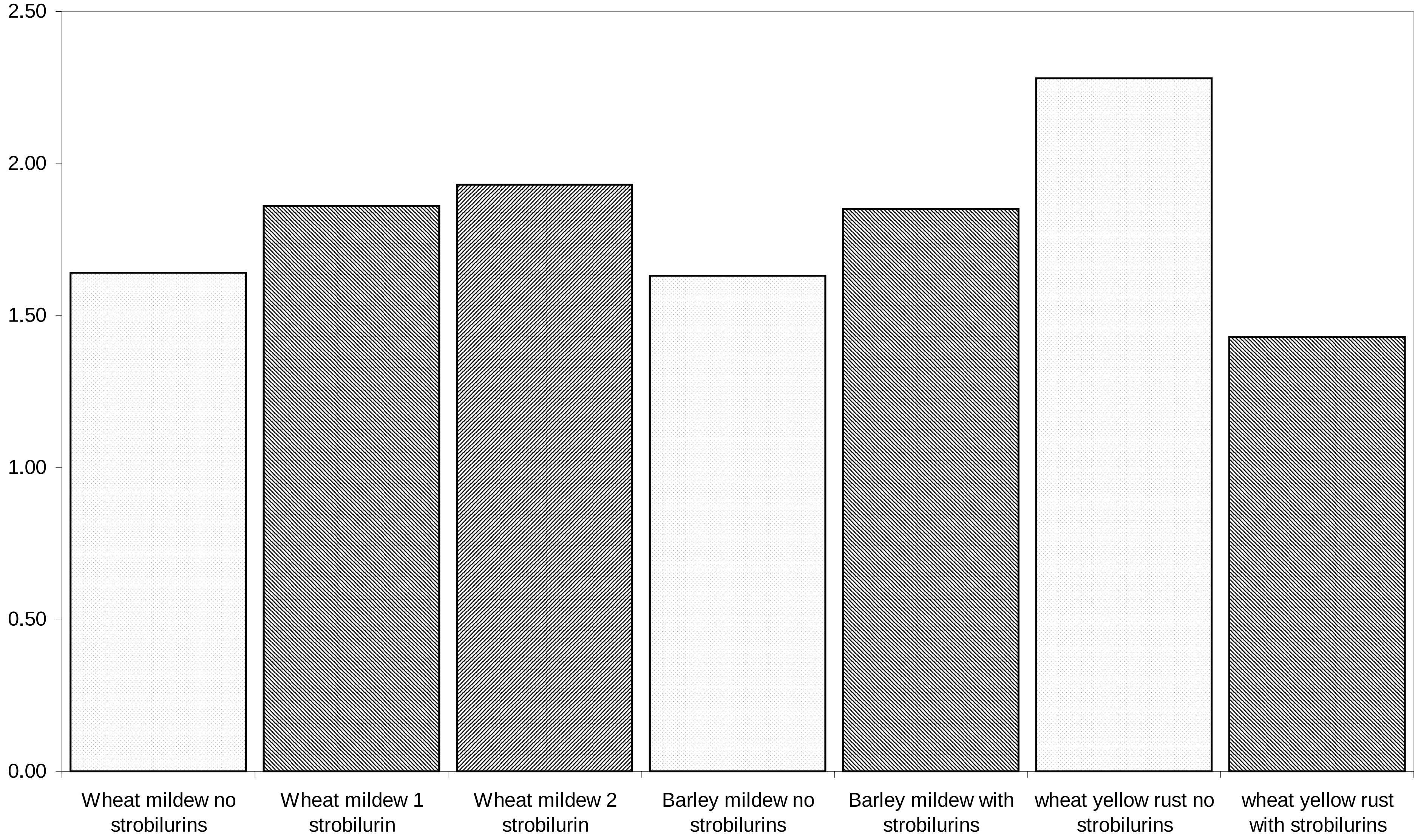


Figure 6. Mean RF values, for strobilurins, for wheat and barley mildew and wheat yellow rust isolates, with and without strobilurins.

Table 9. RF values of the resistant wheat mildew isolates.

		RF		
Isolate	Strobilurin sensitivity	Strobilurin	Morpholine	DMI
WC/3	sensitive	1	1	1
W94/71/3	sensitive	1	3	3
W96/149/3	sensitive	1	5	11
RR99/47	resistant	>32*	7	14
RR99/166	resistant	>32*	4	21
RR99/184	resistant	>32*	7	11

*as there was minimal reduction in growth at the highest rate of strobilurins a true EC_{50} could not be derived.

Glasshouse study at SAC

Table 10. EC_{50} values for treatments applied in glasshouse experiments.

Application number	Treatment	Water control	Amistar 1/32 dose rate	Amistar 1/8 dose rate	Amistar 1/4 dose rate	Amistar 1/2 dose rate	SED *P* value
1	Mixed population	492	841	829	>1600	1205	127.4 0.142
1	Sensitive control	118	113	111	121	120	8.0 0.619
1	Resistant control	1454	1600	1441	1518	1450	151.4 0.808
2	Mixed population	479	751	1069	1518	1347	410.0 0.149
2	Sensitive control	122	117	114	117	126	10.4 0.766
2	Resistant control	1547	1542	>1600	1536	1453	74.2 0.447
3	Mixed population	442	1270	1112	>1600	1485	342.0 0.048
3	Sensitive control	**117**	112	109	119	122	8.2 0.542
3	Resistant control	1520	1532	>1600	>1600	>1600	49.6 0.320

There were several limitations to this experimental work. The most significant was that at spray rates of above twice the full commercial dose rate of Amistar (1600ppm), under glasshouse conditions, serious plant damage occurred so that this was the maximum rate that could be applied. Although the Genstat programme used for EC_{50} analysis still fitted values to the data in many cases there was only a minimal reduction in growth rate at this concentration where the resistant isolate was involved. In many cases the value assigned was >1600ppm and may in fact have been much higher. Even values assigned below 1600ppm were highly variable between replicates and testing times, demonstrating the limitations of the programme in fitting EC_{50} values at an early point in what should have been the dose response curve with most of the actual data points on a flat line. Another limitation of the method was that after treatment the population generated needed for three cycles of growth to generate enough inoculum for testing. This may have allowed some shifts in the populations over this period after treatment and before testing.

DISCUSSION

This project provides an update on the current resistance status of wheat mildew, barley mildew and wheat yellow rust with respect to key fungicide groups in the UK. The sensitivity of both wheat and barley mildew to DMIs and morpholines has clearly shifted since fungicides in these groups were introduced some 30 years ago. This is hardly surprising considering the continuous widespread use of this chemistry over a long period and the intrinsically high resistance risk of the pathogens concerned. The shift towards resistance has been greater for DMIs than for morpholines and for wheat mildew than for barley mildew. Average resistance factors for wheat mildew isolates in 1998/1999 were 31.8 for DMIs and 16.7 for morpholines, indicating a 32-fold or 17-fold increase in the dose of fungicide required to reduce the growth of the pathogen by 50%, when compared with unselected baseline isolates. Comparable resistance factors for barley mildew were 23.5 for DMIs and 10.7 for morpholines. Further monitoring would be needed to determine whether the sensitivity of these pathogens has stabilised or is continuing to decline. With the advent of new chemical groups with activity against mildew, there would seem to be the opportunity to stabilise the position of the older chemistry by use of mixtures and alternations of fungicides with different modes of action.

When the strobilurin sensitivity monitoring described here started, it was widely believed that the risk of resistance to this new chemistry was low. Whether resistance, if it did develop, would do so as a gradual shift or in a single large step, was unknown. However, in the first year of monitoring, 1998, resistance to strobilurins was reported in wheat mildew in Germany and it became clear that resistance is controlled by a major gene and occurs as a single step, resulting in two distinct populations of mildew, i.e. sensitive and resistant. The following year, 1999, this UK project detected resistance in wheat mildew in isolates collected in East Anglia. This was confirmed by monitoring results released by the agrochemical industry’s Fungicide Resistance Action Committee (FRAC), a specialist group of the Global Crop Protection Federation (GCPF) dedicated to prolonging the effectiveness of fungicides liable to encounter resistance problems. Resistant isolates show little or no reduction in growth on seedlings sprayed with azoxystrobin at full dose rate.

Judging by the rate at which resistance in wheat mildew appeared throughout Europe, it seems likely that the incidence of resistance in the UK will increase to high levels within one or two years, rendering strobilurins totally ineffective in controlling mildew. There is clearly a high risk that barley mildew will follow the same course. Isolates of barley powdery mildew resistant to strobilurins have since been identified, by Syngenta, in the north of Scotland (S. Heaney, BCPC 2000 presentation).

One objective of these investigations was to gather evidence on the influence of different fungicide strategies on pathogen sensitivity to strobilurins and the value of these strategies as 'anti-resistance' measures. However, when strobilurin resistance was detected, it proved to be of the major gene type, occurring in a single step rather than by a gradual and progressive shift. During the period of the project, resistance was at only a very low frequency in the wheat mildew population and was undetectable in the barley mildew population. This meant that it was impossible to measure effects of fungicide strategy on the frequency of fully resistant isolates. Despite this, there was some evidence that strobilurin application may produce a slight quantitative shift in sensitivity. The average RF of wheat mildew isolates sampled from plots that had received at least one strobilurin spray had, on average, slightly higher RF. Barley mildew isolates showed a similar, although non-significant, trend.

Mixed spray programmes utilising fungicides with different modes of action are only valuable as an anti-resistance strategy if there is no cross resistance between the fungicides concerned and if combined resistance is uncommon. There was no evidence here of cross resistance between DMIs, morpholines and strobilurins. However, it appears that the general shift in the mildew populations away from sensitivity to the DMIs and morpholines has resulted in a significant proportion of isolates showing reduced sensitivity to both chemicals i.e. combined resistance. Combined resistance is random whereas cross resistance is where there is a link between modes of action.

The glasshouse dose and application number experiments had several limitations. The most significant was that at spray rates of above twice the full commercial dose rate of Amistar (1600ppm), under glasshouse conditions, serious plant damage occurred so that this was the maximum rate that could be applied. Although the Genstat programme used for EC_{50} analysis still fitted values to the data in many cases there was only a minimal reduction in growth rate at this concentration where the resistant isolate was involved. In many cases the value assigned was >1600ppm and may in fact have been much higher. Even values assigned below 1600ppm were highly variable between replicates and testing times, demonstrating the limitations of the programme in fitting EC_{50} values at an early point in what should have been the dose response curve with most of the actual data points on a flat line. Another limitation of the method was that after treatment the population generated needed for three cycles of growth to generate enough inoculum for testing. This may have allowed some shifts in the populations over this period after treatment and before testing.

There were no significant differences relating to fungicide treatments and application number for the sensitive and resistant controls, demonstrating that within the limits of the experimental technique there was no influence of dose and application number on an entirely sensitive or entirely resistant population. After three application timings the resistant isolates treated with the water control had a trend towards having lower EC_{50} values than the fungicide treatments which may support the theory that the resistance is enhanced by applications of the fungicide.

Where the mixed populations were tested there were only significant differences between the water control and the other fungicide treatments after three applications. The water control EC_{50} for the mixed population did not change significantly over the experimental period which may demonstrate that resistance is stable in the population in the absence of fungicide and implies that there was no fitness penalty over the limited time scale of the project. There was a significant increase in the EC_{50} value following three applications of fungicide regardless of the dose rate applied. After one and two applications of the fungicide there was a trend, although not significant, for the lower fungicide concentrations to result in lower EC_{50} values which may imply that more of the sensitive population survived in the mixed population at these low dose rates. At the highest dose rates applied the EC_{50} values for the mixed population after one application was similar to the resistant control isolates which could imply none of the sensitive population had survived. The proportion of resistant isolates in the mixed populations was mixed by weight to be 10% of the total. It could be that this was too high a proportion to pick out influences of dose rate and application number in the very early stages of resistance development. Five percent is accepted by the companies as being a level of resistance that will cause problems in field performance. If the experiments could be repeated it might be interesting to investigate a much lower inclusion of resistant isolates.

Over the last ten years there has been a clear shift in the sensitivity of wheat yellow rust population towards insensitivity to DMI fungicides (B. Napier *et al*., 2000) in the wheat yellow rust population. A combination of cultivar susceptibility and weather conditions, together with a tendency for fungicides to be used at rates well below those recommended, resulted in widespread yellow rust infection and inadequate control. In response to the high disease risk, DMIs were used repeatedly in many crops, starting with seed dressings and followed by foliar applications. On theoretical grounds, prolonged exposure to a fungicide is generally believed to increase selection for insensitivity and may well have contributed to the shift observed.

Although there have been no confirmed cases of insensitivity causing failure of yellow rust control in the field, it is clearly important that every effort should be made to halt the sensitivity shift. Appropriate anti-resistance measures include growing resistant varieties, following the principles of variety diversification and spraying at the first signs of infection using adequate dose rates. Repeated applications of DMIs alone should be avoided by using co-formulations, recommended tank-mixes or sequences of sprays which bring together different modes of action effective against yellow rust (FRAG-UK, 2000).

There was no evidence of wheat yellow rust insensitivity to strobilurins, although the DMI evidence suggests that changes in sensitivity for yellow rust occur over a larger time scale than for powdery mildew. There is a clear risk that yellow rust may develop resistance to strobilurins and this is likely to occur as a single-step process.

Resistance management strategies, based on fungicide programmes, are dependent upon the availability of chemicals with different modes of action. By using tank mixtures of fungicide or not using the same fungicide on multiple occasions within a season the risk of resistant isolates developing can be reduced. The use of cultural controls e.g. growing cultivars resistant to the pathogens; removal of plant debris, etc. must form a part of disease control to reduce the use of fungicides so their efficacy can be maintained over a longer period.

It is essential that independent monitoring of new and existing fungicides be continued to ensure a rapid response to any pathogen resistance that may develop. Once sensitivity to a chemical is compromised it is unlikely that any reversal can be effected. Therefore it is important to have an early warning in order prolong the life of fungicides.

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APPENDIX 1

NIAB Winter Barley treatments sampled in 1998

Treatment	Spray Timing (GS)	Product	Rate (l/ha)
Untreated		nil	
2	31	Opus + Bavistan DF + Corbel	1.0 + 500(g/ha) + 0.5
	39	Opus Team	1.5
4	31	Landmark	1.0
	49	Landmark	0.5
6 and S	31	Amistar Pro	2.0
	49	Amistar Pro	1.5
7	31	Landmark + Amistar	0.5 + 0.5
	49	Opus Team	1.5

NIAB Winter Barley treatments sampled in 1999

Treatment	Spray Timing (GS)	Product	Rate (l/ha)
Untreated		nil	
2	31	Opus + Unix + Corbel	0.5 + 670(g/ha) + 0.5
	39-49	Opus Team	1.5
3	31	Amistar Pro + Unix	2.0 + 670(g/ha)
	39-49	Amistar Pro	2.0
4	31	Mantra + Unix	0.75 + 670(g/ha)
	39-49	Mantra	1.0
7	31	Unix + StrobA* + Tilt	670(g/ha) + 1.5 + 0.5
	39-49	StrobB*	1.0
9	30-31	Fortress	0.15
	39-49	Opus + Bravo	0.5 + 1.0
T	autumn	Unix + Corbel	670(g/l) + 0.75
	31	Amistar Pro + Unix	2.0 + 670(g/ha)
	45-59	Amistar Pro	2.0
A	oct/nov	Tilt + Calixin	0.5 + 0.5
	31	Opus + Bavistan DF + Corbel	1.0 + 500(g/ha) + 0.5
	39-45	Opus Team	1.5

* experimental product

NIAB Winter Wheat treatments sampled in 1998

Treatment	Spray Timing (GS)	Product	Rate (l/ha)
Untreated		nil	
2	31	Bravo + Sportak delta + Patrol	1.0 + 1.25 + 0.5
	39	Opus Team	1.5
	59	Folicur	0.75
4 and S	31	Landmark	1.0
	39	Landmark	1.0
	59	Amistar	0.5
6	31	Amistar Pro + Pointer	1.5 + 0.5
	39	Amistar Pro + Opus	1.0 + 0.5
	59	Amistar	1.5
7	31	Bravo + Sportak delta + Patrol	1.0 + 1.25 + 0.5
	39	Landmark + Amistar	0.5 + 0.5
	59	Folicur	0.75

Other Winter Wheat trials 1998

BASF demonstration plots at Upton, Cambs.

Bayer demonstration plots at Long Sutton, Lincs.

B. Butlin demonstration plots Lincs.

The exact treatments from these trials are confidential.

NIAB Winter Wheat treatments sampled in 1999

Treatment	Spray Timing (GS)	Product	Rate (l/ha)
Untreated		nil	
2	31-32	Bravo + Unix + Opus Team	1.0 +1.0(kg/ha) + 0.75
	39	Opus Team	1.5
	59	Folicur	0.75
3	31-32	Mantra + Unix	0.75 + 1.0(kg/ha)
	39	Mantra	1.0
	59	Folicur	0.75
6	31-32	Amistar + Opus	0.6 + 0.5
	39	Amistar + Opus	1.0 + 0.5
	59	Folicur	0.5
7	31-32	Opus + Bravo 500	0.5 + 1.5
	39	Amistar + Opus	1.0 + 0.5
	59	Amistar	0.5
8	31-32	Unix + Menara	670(g/ha) + 0.25
	39	StrobA* + Opus	1.2 + 0.5
	59	StrobA* + Plover	0.6 + 0.2
9	31-32	Unix + Menara	670(g/ha) + 0.25
	39	StrobA* + Opus	1.2 + 0.5
	59	MBC + Plover	125(g/ha) + 0.3
10	31-32	StrobC*	0.6
	39	StrobA* + Opus	1.2 + 0.5
	59	MBC + Plover	125(g/ha) + 0.3
11	30-31	Fortress	0.15
	39	Opus + Bravo	0.5 + 1.0
T (Full)	31-32	Bravo + Opus + Unix	1.0 + 0.5 + 1.0(kg/ha)
	39	Mantra	1.0
	59	Amistar + Folicur	0.5 + 0.5

* experimental product

T (Full) – samples were also taken from plots with ½ and ¼ rates

NIAB Spring Barley treatments sampled in 1999

Treatment	Spray Timing (GS)	Product	Rate (l/ha)
Untreated		nil	
2 and A	30-31	Punch C + Corbel	0.625 + 0.75
	39-49	Opus Team	1.5
3 and T	30-31	Amistar Pro + Unix	2.0 + 670(g/ha)
	45-59	Amistar Pro	2.0

APPENDIX 2

SAC Field Trial details 1998

Winter wheat

Variety Riband

Number of replicates 3

Bielgrange, East Lothian

Treatment	T1 GS 31 23 Apr 99	Product rate (l/ha)	T2 GS 39 03 Jun 99	Product rate (l/ha)
1	untreated		untreated	
2	Amistar + Opus	0.5 + 0.5	Amistar + Opus	0.75 + 0.3
3	Amistar + Opus	0.5 + 0.5	Opus	0.75
4	Landmark	0.5	Opus	0.75
5	Amistar + Opus	0.5 + 0.5	Landmark	0.75
6	Landmark	0.5	Landmark	0.75
7	Sportak delta	0.9	Opus	0.75
8	Sportak delta	0.9	Landmark	0.75
9	Landmark	0.75	Amistar + Opus	0.75 + 0.3

Spring Barley Site: March Park, Boghall farm, Biggar Road, EH10 7DX

Grid ref: NT 249659

Treatment	T1 GS 31	Product rate (l/ha)	T2 GS 39	Product rate (l/ha)
1	untreated		untreated	
2	Sanction + Corbel	0.3 + 0.5	Opus + Corbel	0.15 + 0.25
3	Landmark	0.75	Landmark	0.75
4	Ensign	0.35	Ensign	0.35
5	Amistar + Corbel	0.5 + 0.25	Amistar + Corbel	0.5 + 0.25
6	Sanction + Fortress	0.15 + 0.1	Sanction + Corbel	0.15 + 0.25
7	Opus + Unix	0.3 + 0.4 (kg)	Sanction + Corbel	0.15 + 0.25

SAC Field Trial details 1999

Site: March Park, Boghall farm, Biggar Road, EH10 7DX

Grid ref: NT 249659

Crop: Barley

Variety: Regina

Treatment	GS 31-32 Product + rate (l/ha)	GS 39-45 Product + rate (l/ha)
1	nil	nil
2	Punch C 0.4 + Corbel 0.4	Punch C 0.4 + Corbel 0.4
3	Amistar pro 1.0	Amistar pro 1.0
4	Amistar pro 1.5	Amistar pro 1.5

Crop: Spring barley

variety: Delibes

Treatment	GS 30 Product + rate (l/ha)	GS 39 Product + rate (l/ha)
1	nil	nil
2	nil	Ensign 0.5 + Sanction 0.3
3	Ensign 0.5 + Sanction 0.3 + Corbel 0.25	Ensign 0.5 + Sanction 0.3 + Corbel 0.25

Site: Fans Farm, Earlston, Berwickshire

grid ref: NT 613 402

crop: Winter barley

Variety Muscat

Treatment	GS 31-32 Product + rate (l/ha)	GS 39-45 Product + rate (l/ha)
1	nil	nil
2	Unix 0.5 + Corbel 0.4	Amistar Pro 1.0

Crop Wheat

Variety Riband

Treatment	GS 32 Product + rate (l/ha)	GS 39 Product + rate (l/ha)	GS 59 Product + rate (l/ha)
1	nil	nil	nil
2	Unix 0.5 + Opus 0.3	Landmark 0.75	Amistar 0.3
3	Unix 0.5 +Opus 0.3	Opus 0.75 + Bravo 1.0	Amistar 0.3
4	Unix 0.5 +Opus 0.3	Amistar 0.75 + Opus 0.3	Amistar 0.3
5	Unix 0.3 + Opus 0.3	Landmark 0.5	Amistar 0.3
6	Unix 0.3 +Opus 0.3	Amistar 0.5 + Opus 0.3	Amistar 0.3

Crop: Spring barley

Variety: Prisma

Treatment	GS 30 Product + rate (l/ha)	GS 39 – 49 Product + rate (l/ha)
1	nil	nil
2	Amistar 0.6 + Orka 1.0	Amistar 0.6 + Orka 1.0
3	Amistar 0.3 +Orka 1.0	Amistar 0.3 +Orka 1.0

Site: Markle Mains Farm, Markle, East Linton, East Lothian.

Grid ref: NT 5588 771

Crop: Winter wheat

Variety: Riband

Treatment	GS 32 Product + rate (l/ha)	GS 39 Product + rate (l/ha)	GS 55 Product + rate (l/ha)
1	nil	nil	nil
2	Unix 0.5 + opus 0.5	Amistar 0.5 + Opus 0.3	Amistar 0.3

Site: Biel Grange Farm, Dunbar, East Lothian

Grid ref: NT 608 758

Crop: Winter wheat

Variety: Consort

Treatment	GS 32	GS 39	GS 59
	Product + rate (l/ha)	Product + rate (l/ha)	Product + rate (l/ha)
1	nil	nil	nil
2	Unix 0.5 + Opus 0.3	Amistar 0.75 + Opus 0.3	Amistar 0.3
3	Unix 0.3 + Opus 0.3	Amistar 0.5 + Opus 0.3	Amistar 0.3
4	Unix 0.5 + Opus 0.3	Landmark 0.75	Amistar 0.3

Crop: Winter wheat

Variety: Riband

Treatment	GS 32	GS 39	GS 59
	Product + rate (l/ha)	Product + rate (l/ha)	Product + rate (l/ha)
1	nil	nil	nil
2	Unix 0.5 + Opus 0.3	Amistar 0.8 + Opus 0.3	Amistar 0.3
3	Unix 0.3 + Opus 0.3	Amistar 0.6 + Opus 0.3	Amistar 0.3
4	Unix 0.5 + Opus 0.3	Landmark 0.75	Amistar 0.3

Crop: Spring barley

Variety: Optic

Treatment	GS 24-30	GS 33	GS 39-49
	Product + rate (l/ha)	Product + rate (l/ha)	Product + rate (l/ha)
1	nil	nil	nil
2	Amistar 0.6 + Corbel 0.5	nil	Amistar 0.6 + Corbel 0.5
3	Punch C 0.6 25 + Corbel 0.5	nil	Punch C 0.6 25 + Corbel 0.5
4	nil	Amistar 0.8 + Opus 0.75	nil
5	Amistar 0.4	Amistar 0.4	Amistar 0.4
6	Amistar 0.6	Amistar 0.6	Amistar 0.6
7	Amistar 0.8	Amistar 0.8	Amistar 0.8

APPENDIX 3

Wheat mildew isolate details

Isolate code	Year	Sampling time	Trial identification	Geographic location	Strobilurin?	if strobilurin, +/- morpholine	if strobilurin, +/- DMI	Fungicide treatment **prior to sampling**: Strobilurin timing and dose – GS31	GS37/39	later	RF: azoxystrobin	RF: morpholine	RF: DMI
SH1	8	E	Seale Hayne	E							0.9	12.4	7.7
CP1	8	E	Cockle Park	E							2.3	9.3	21.7
BB U	8	E	B. Butlins	E							1.1	5.9	13.9
HH T	8	E	H. Hall	E	O						1.1	10.6	28.6
M2	8	E	Morley	E	O						1.7	6.4	50.0
CP2	8	E	Cockle Park	E	O						1.9	6.3	15.4
BB Tri	8	E	B. Butlins	E	O						0.5	5.5	10.0
G2	8	E	Gwent	E	O						0.7	3.6	50.0
CP6	8	E	Cockle Park	E	S	M	T	H	H	H	4.6	18.2	26.0
CP7	8	E	Cockle Park	E	S	M	T		H		1.5	9.6	35.2
HH S	8	E	H. Hall	E	S		T	H	H	H	1.6	9.4	24.0
BB Km	8	M	B. Butlins	E	S		T	H	H		1.4	8.7	14.0
CP4	8	E	Cockle Park	E	S		T	H	H	H	2.4	8.6	10.7
B7	8	E	Bridgets	E	S	M	T		H		1.8	8.3	21.1
B6	8	E	Bridgets	E	S	M	T	H	H	H	0.6	6.3	11.3
LS S	8	E	Long Sutton	E	S		T	H	H	H	1.5	5.7	36.7
G7	8	E	Gwent	E	S	M	T		H		1.0	4.6	34.7
RR99/1	9	B	HQTG	E							1.16		
RR99/2	9	B	HQTG	E							0.96		
RR99/3	9	B	Morley	E							1.09		
RR99/4	9	B	Morley	E							0.99		
RR99/5	9	B	Morley	E							1.39		
RR99/6	9	B	Wye	E							0.66		
RR99/7	9	B	H. Hall	E							0.75		
RR99/8	9	B	H. Hall	E							1.78		
RR99/9	9	B	H. Hall	E							0.87		
RR99/10	9	B	Gwent	E							2.0		
RR99/11	9	B	Gwent	E							1.92		
RR99/12	9	B	Gwent	E							1.54		
RR99/13	9	B	Bridgets	E							0.53		
RR99/14	9	B	Bridgets	E							6.20		
RR99/15	9	B	Bridgets	E							1.99		
RR99/16	9	B	Bridgets	E							3.41		
RR99/17	9	B	Bridgets	E							5.12		
RR99/18	9	B	Bridgets	E							0.87		
RR99/19	9	M	Wye	E	S		T		H		0.92		

RR99/20	9	M	Wye	E	S	M	T	H	H		0.85		
RR99/21	9	M	Wye	E	S		T		H		1.53		
RR99/22	9	M	Wye	E	O						2.06		
RR99/23	9	M	Wye	E	O						1.42		
RR99/24	9	M	Wye	E	S		T		H		1.01		
RR99/25	9	M	Wye	E	S		T		H		0.71		
RR99/26	9	M	Wye	E	S		T		H		1.61		
RR99/27	9	M	Wye	E	O						1.13		
RR99/28	9	M	Wye	E	S		T		H		0.69		
RR99/29	9	M	Wye	E	O						1.34		
RR99/30	9	M	Wye	E	S		T	H	H		0.45		
RR99/31	9	M	Wye	E	S		T		H		0.44		
RR99/32	9	M	Wye	E	S	M	T	H	H		0.65		
RR99/33	9	M	Wye	E	O						2.14		
RR99/34	9	M	Wye	E	O						1.63		
RR99/35	9	M	Wye	E	S		T		H		2.30		
RR99/36	9	M	Wye	E	S		T	H	H		2.25		
RR99/37	9	M	Wye	E	S	M	T	H	H		2.06		
RR99/38	9	M	Wye	E	S		T	H	H		1.44		
RR99/39	9	M	Wye	E	S		T		H		1.23		
RR99/40	9	M	Wye	E	S		T	H	H		2.05		
RR99/41	9	M	Wye	E	S		T	H	H		0.90		
RR99/42	9	M	Wye	E	S		T	H	H		1.78		
RR99/43	9	M	Morley	E	S		T		H		0.63		
RR99/44	9	M	Morley	E	S		T	H	H		2.38		
RR99/45	9	M	Morley	E	S		T		H		1.37		
RR99/46	9	M	Morley	E	S		T	H	H		2.68		
RR99/47	9	M	Morley	E	S		T		H		34.9		
RR99/48	9	M	Morley	E	S		T		H		0.73		
RR99/49	9	M	Morley	E	S		T		H		1.85		
RR99/50	9	M	Morley	E	S		T		H		1.94		
RR99/51	9	M	Morley	E	S		T		H		2.87		
RR99/52	9	M	Morley	E	S		T	H	H		2.00		
RR99/53	9	M	Morley	E	S		T		H		1.82		
RR99/54	9	M	Morley	E	S		T		H		1.98		
RR99/55	9	M	Morley	E	S		T		H		0.72		
RR99/56	9	M	Morley	E	S		T		H		2.53		
RR99/57	9	M	Morley	E	S		T	H	H		3.21		
RR99/59	9	M	Morley	E	S		T		H		1.68		
RR99/60	9	M	Morley	E	S		T	H	H		2.73		
RR99/61	9	M	Morley	E	S		T		H		0.99		
RR99/63	9	M	Morley	E	S	M	T		H		2.23		
RR99/65	9	M	Morley	E	S	M	T		H		1.44		
RR99/66	9	M	Morley	E	S	M	T		H		0.73		
RR99/67	9	M	Morley	E	S	M	T		H		1.33		
RR99/69	9	M	Morley	E	S	M	T		H		1.99		
RR99/70	9	M	Hilton	E	S			L			2.1		
RR99/71	9	s	Fen Ditton	E	S			L			1.2		
RR99/72	9	s	Fen Ditton	E	S			L			2.22		
RR99/73	9	M	H. Hall	E	S	M	T		H		1.85		
RR99/74	9	M	H. Hall	E	S	M	T		L		4.55		
RR99/75	9	M	H. Hall	E	S	M	T		H		8.83		

RR99/76	9	M	H. Hall	E	S	M	T		H		1.35		
RR99/77	9	M	H. Hall	E	S	M	T		H		0.98		
RR99/78	9	M	H. Hall	E	S	M	T		L		1.08		
RR99/79	9	M	H. Hall	E	S	M	T		H		2.35		
RR99/80	9	M	H. Hall	E	S	M	T		H		1.21		
RR99/81	9	M	H. Hall	E	S	M	T		L		2.00		
RR99/82	9	E	Morley	E	S		T	H	H		5.30		
RR99/83	9	E	Morley	E	S		T		H		2.16		
RR99/84	9	E	Morley	E	S		T	H	H		2.49		
RR99/85	9	E	Morley	E	S	M	T	H	H		1.52		
RR99/86	9	E	Morley	E	S		T		H	H	1.41		
RR99/87	9	E	Morley	E	S		T		H		1.28		
RR99/88	9	E	Morley	E	S		T		H		1.29		
RR99/89	9	E	Morley	E	S	M	T	H	H		1.55		
RR99/90	9	E	Morley	E	S		T		H		1.68		
RR99/91	9	E	Morley	E	S		T		H		0.82		
RR99/92	9	E	Morley	E	S		T	H	H		1.43		
RR99/93	9	E	Morley	E	S		T	H	H		2.19		
RR99/94	9	E	Morley	E	S		T		H	H	1.86		
RR99/95	9	E	Morley	E	S		T		H		2.42		
RR99/96	9	E	Morley	E	S		T		H		1.47		
RR99/97	9	E	Morley	E	S		T		H	H	0.84		
RR99/98	9	E	Morley	E	S		T	H	H		0.94		
RR99/99	9	E	Morley	E	S		T		H		0.75		
RR99/101	9	E	Morley	E	S		T		H		4.64		
RR99/102	9	E	Morley	E	S		T		H		2.00		
RR99/103	9	E	Morley	E	S	M	T		H	H	3.10		
RR99/104	9	E	Morley	E	S	M	T		H	L	1.79		
RR99/105	9	E	Morley	E	S	M	T		H	L	1.51		
RR99/106	9	E	Morley	E	S	M	T		H	H	2.64		
RR99/107	9	E	Morley	E	S	M	T		H	H	2.61		
RR99/108	9	E	Morley	E	S	M	T		H	L	1.69		
RR99/109	9	E	Gwent	E	S		T		H	H	1.74		
RR99/110	9	E	Gwent	E	O						2.29		
RR99/112	9	E	Gwent	E	O						3.39		
RR99/114	9	E	Gwent	E	O						2.13		
RR99/115	9	E	Gwent	E	S		T	H	H		0.67		
RR99/116	9	E	Gwent	E	O						1.91		
RR99/119	9	E	Bridgets	E	S		T		H	H	2.18		
RR99/120	9	E	Bridgets	E	S		T	H	H		1.95		
RR99/121	9	E	Bridgets	E	S		T		H		2.10		
RR99/122	9	E	Bridgets	E	O						0.79		
RR99/123	9	E	Bridgets	E	S		T	H	H		0.32		
RR99/124	9	E	Bridgets	E	S		T		H		1.67		
RR99/126	9	E	Bridgets	E	O						2.37		
RR99/127	9	E	Bridgets	E	S		T		H		1.62		
RR99/128	9	E	Bridgets	E	S		T	H	H		0.61		
RR99/129	9	E	Bridgets	E	S		T	H	H		2.20		
RR99/131	9	E	Bridgets	E	O						0.46		
RR99/132	9	E	Bridgets	E	S		T	H	H		1.96		
RR99/133	9	E	Bridgets	E	O						1.51		
RR99/134	9	E	Bridgets	E	S		T	H	H		2.86		

RR99/136	9	E	Bridgets	E	S	M	T	H	H		2.60		
RR99/137	9	E	Bridgets	E	S		T		H		2.13		
RR99/138	9	E	Bridgets	E	S		T		H	H	2.55		
RR99/139	9	E	Bridgets	E	S	M	T		H	H	1.00		
RR99/140	9	E	Bridgets	E	S	M	T		H	H	2.55		
RR99/141	9	E	Bridgets	E	S	M	T		L	L	1.61		
RR99/142	9	E	Bridgets	E	S	M	T		L	L	4.02		
RR99/144	9	E	Bridgets	E	S	M	T		H	H	1.29		
RR99/145	9	E	Bridgets	E	S	M	T		L	L	2.03		
RR99/146	9	E	Bridgets	E	S	M	T		H	H	1.23		
RR99/147	9	E	Bridgets	E	S	M	T		H	H	1.16		
RR99/148	9	E	Wye	E	S		T		H		1.17		
RR99/149	9	E	Wye	E	S	M	T	H	H		2.17		
RR99/150	9	E	Wye	E	S		T		H		2.15		
RR99/151	9	E	Wye	E	O						1.58		
RR99/152	9	E	Wye	E	O						3.70		
RR99/153	9	E	Wye	E	S		T		H		1.83		
RR99/154	9	E	Wye	E	S		T		H		1.15		
RR99/155	9	E	Wye	E	S		T		H	H	1.75		
RR99/156	9	E	Wye	E	O						1.56		
RR99/157	9	E	Wye	E	S		T		H	H	0.94		
RR99/159	9	E	Wye	E	S		T	H	H		3.64		
RR99/160	9	E	Wye	E	S		T		H		2.84		
RR99/161	9	E	Wye	E	S	M	T	H	H		6.48		
RR99/162	9	E	Wye	E	O						2.17		
RR99/164	9	E	Wye	E	S		T		H		2.25		
RR99/165	9	E	Wye	E	S		T	H	H		2.25		
RR99/166	9	E	Wye	E	S	M	T	H	H		25.1		
RR99/167	9	E	Wye	E	S		T	H	H		0.74		
RR99/168	9	E	Wye	E	S		T		H	H	2.57		
RR99/169	9	E	Wye	E	S		T	H	H		5.34		
RR99/170	9	E	Wye	E	S		T	H	H		1.72		
RR99/171	9	E	Wye	E	S		T	H	H		3.86		
RR99/172	9	E	H. Hall	E	S	M	T		H	H	2.95		
RR99/173	9	E	H. Hall	E	S	M	T		L	L	1.94		
RR99/174	9	E	H. Hall	E	S	M	T		H	H	1.55		
RR99/175	9	E	H. Hall	E	S	M	T		H	H	1.13		
RR99/176	9	E	H. Hall	E	S	M	T		H	H	1.68		
RR99/177	9	E	H. Hall	E	S	M	T		L	L	1.04		
RR99/179	9	E	H. Hall	E	S	M	T		H	H	2.05		
RR99/180	9	E	H. Hall	E	S	M	T		L	L	1.07		
RR99/182	9	s	Fen Ditton	E	S			L			2.16		
RR99/183	9	s	Harston	E	S			L			3.00		
RR99/184	9	s	Fen Ditton	E	S			L			22.2		
RW98/01	8	B	Ratho	S							1.07	22.6	35.6
RW98/02	8	B	Ratho	S							1.53	10.4	10.3
RW98/03	8	B	Ratho	S							0.87	8.1	11
RW98/04	8	B	Ratho	S							1.10	25	14.5
RW98/05	8	M	Ratho	S	S		T	L	H		2.07	11.9	50.9
RW98/06	8	M	Ratho	S	S		T	L	H		1.45	15.2	15.8
RW98/07	8	M	Ratho	S	S		T	L	H		0.53	5.6	28.7
RW98/08	8	M	Ratho	S	S		T	L	H		0.75	27.8	41.1

RW98/09	8	M	Ratho	S	S		T	L			2.30	20.5	45.6
RW98/10	8	M	Ratho	S	S		T	L			0.7	18.3	27.8
RW98/11	8	M	Ratho	S	S		T	L			2.10	20.5	22.4
RW98/12	8	M	Ratho	S	S		T	L			1.43	15.8	33.9
RW98/13	8	M	Ratho	S	S		T	L			2.01	19.7	35.7
RW98/14	8	M	Ratho	S	S		T	L			4.56	32	50.6
RW98/15	8	M	Ratho	S	S		T	L			1.32	25.4	17.2
RW98/16	8	M	Ratho	S	S		T	L			2.37	17.6	52.8
RW98/17	8	M	Ratho	S	S		T	L	H		1.84	11.4	21.5
RW98/18	8	M	Ratho	S	S		T	L	H		0.97	9.08	10.3
RW98/19	8	M	Ratho	S	S		T	L	H		2.51	16.3	21.6
RW98/20	8	M	Ratho	S	S		T	L	H		3.50	10.3	18.7
RW98/21	8	M	Ratho	S	S		T	L	H		2.51	8.7	36.7
RW98/22	8	M	Ratho	S	S		T	L	H		2.05	17.8	43.5
RW98/23	8	M	Ratho	S	S		T	L	H		1.77	24.3	33.5
RW98/24	8	M	Ratho	S	S		T	L	H		0.75	9.62	26.4
RW98/25	8	M	Ratho	S	O						0.99	2.11	40.6
RW98/26	8	M	Ratho	S	O						1.20	17.3	27.2
RW98/27	8	M	Ratho	S	O						1.15	34.1	50.1
RW98/28	8	M	Ratho	S	O						2.05	7.45	60.5
RW98/29	8	M	Ratho	S	S		T		H		1.23	32	28.2
RW98/30	8	M	Ratho	S	S		T		H		1.42	25.8	24.8
RW98/31	8	M	Ratho	S	S		T		H		3.41	15.6	17.2
RW98/32	8	M	Ratho	S	S		T		H		1.78	26.5	29
RW98/33	8	M	Ratho	S	S		T	H	H		1.16	10.5	19.5
RW98/34	8	M	Ratho	S	S		T	H	H		4.65	28.3	36.3
RW98/35	8	M	Ratho	S	S		T	H	H		0.74	12.2	30.7
RW98/36	8	M	Ratho	S	S		T	H	H		5.64	32.1	43.5
RW98/37	8	M	Ratho	S							0.98	19.1	39.8
RW98/38	8	M	Ratho	S							3.20	9.5	27.8
RW98/39	8	M	Ratho	S							1.10	10.9	30.7
RW98/40	8	M	Ratho	S							2.57	11.6	49.6
RW98/41	8	E	Ratho	S	S		T	L	H		1.56	12.3	38.9
RW98/42	8	E	Ratho	S	S		T	L	H		0.67	8.5	37.5
RW98/43	8	E	Ratho	S	S		T	L	H		2.65	14.4	123.8
RW98/44	8	E	Ratho	S	S		T	L	H		1.05	98.5	33.9
RW98/45	8	E	Ratho	S	S		T	L			3.25	22.6	43.1
RW98/46	8	E	Ratho	S	S		T	L			3.07	20.4	24.8
RW98/47	8	E	Ratho	S	S		T	L			2.95	10.6	29.3
RW98/48	8	E	Ratho	S	S		T	L			2.85	19.5	63.2
RW98/49	8	E	Ratho	S	S		T	L			1.22	14.1	27.6
RW98/50	8	E	Ratho	S	S		T	L			1.81	11.6	54.8
RW98/51	8	E	Ratho	S	S		T	L			5.04	20.5	15.2
RW98/52	8	E	Ratho	S	S		T	L			4.43	17.9	28.7
RW98/53	8	E	Ratho	S	S		T	L	H		3.21	14.3	25.6
RW98/54	8	E	Ratho	S	S		T	L	H		1.91	30.1	43.7
RW98/55	8	E	Ratho	S	S		T	L	H		0.95	27.8	28.9
RW98/56	8	E	Ratho	S	S		T	L	H		1.28	16.4	14.1
RW98/57	8	E	Ratho	S	S		T	L	H		1.85	22.8	32.4
RW98/58	8	E	Ratho	S	S		T	L	H		1.29	15.3	16.2
RW98/59	8	E	Ratho	S	S		T	L	H		2.10	12.7	19.5
RW98/60	8	E	Ratho	S	S		T	L	H		1.78	8.32	41.8

RW98/61	8	E	Ratho	S	O						0.99	27.1	50.2
RW98/62	8	E	Ratho	S	O						0.74	28.3	14
RW98/63	8	E	Ratho	S	O						0.76	21.6	19.6
RW98/64	8	E	Ratho	S	O						0.95	16.4	27.3
RW98/65	8	E	Ratho	S	S		T		H		1.95	15.7	17.7
RW98/66	8	E	Ratho	S	S		T		H		2.8	27.3	32.4
RW98/67	8	E	Ratho	S	S		T		H		0.7	11.9	40.7
RW98/68	8	E	Ratho	S	S		T		H		1.34	8.7	60.4
RW98/69	8	E	Ratho	S	S		T	H	H		2.06	24.6	24
RW98/70	8	E	Ratho	S	S		T	H	H		2.25	17.3	18.6
RW98/71	8	E	Ratho	S	S		T	H	H		1.79	19.8	50.3
RW98/72	8	E	Ratho	S	S		T	H	H		0.63	16.4	49.8
RW98/73	8	E	Ratho	S							0.95	12.9	37.6
RW98/74	8	E	Ratho	S							1.39	10	32.3
RW98/75	8	E	Ratho	S							0.75	26.2	39.5
RW98/76	8	E	Ratho	S							1.78	11.5	27.8
FW99/01	9	B	FANS	S							1.10		
FW99/02	9	B	FANS	S							0.92		
FW99/03	9	B	FANS	S							3.79		
FW99/04	9	B	FANS	S							0.87		
FW99/05	9	M1	FANS	S							1.75		
FW99/06	9	M1	FANS	S							2.51		
FW99/07	9	M1	FANS	S							1.74		
FW99/08	9	M1	FANS	S							2.24		
FW99/09	9	M1	FANS	S			T				1.35		
FW99/10	9	M1	FANS	S			T				2.55		
FW99/11	9	M1	FANS	S			T				1.61		
FW99/12	9	M1	FANS	S			T				0.94		
FW99/13	9	M1	FANS	S							0.69		
FW99/14	9	M1	FANS	S							0.76		
FW99/15	9	M1	FANS	S							5.15		
FW99/16	9	M1	FANS	S							3.51		
FW99/17	9	M1	FANS	S			T				1.01		
FW99/18	9	M1	FANS	S			T				0.98		
FW99/19	9	M1	FANS	S			T				1.95		
FW99/20	9	M1	FANS	S			T				1.00		
FW99/21	9	M1	FANS	S			T				1.61		
FW99/22	9	M1	FANS	S			T				0.94		
FW99/23	9	M1	FANS	S			T				2.10		
FW99/24	9	M1	FANS	S			T				1.57		
FW99/25	9	M1	FANS	S			T				1.45		
FW99/26	9	M1	FANS	S			T				0.89		
FW99/27	9	M1	FANS	S			T				1.24		
FW99/28	9	M1	FANS	S			T				2.55		
FW99/29	9	M2	FANS	S							1.48		
FW99/30	9	M2	FANS	S							1.94		
FW99/31	9	M2	FANS	S							2.15		
FW99/32	9	M2	FANS	S							1.25		
FW99/33	9	M2	FANS	S	S		T		H		2.25		
FW99/34	9	M2	FANS	S	S		T		H		2.18		
FW99/35	9	M2	FANS	S	S		T		H		2.60		
FW99/36	9	M2	FANS	S	S		T		H		1.74		

FW99/37	9	M2	FANS	S							1.69		
FW99/38	9	M2	FANS	S							2.29		
FW99/39	9	M2	FANS	S							1.74		
FW99/40	9	M2	FANS	S							0.95		
FW99/41	9	M2	FANS	S	S		T		H		4.02		
FW99/42	9	M2	FANS	S	S		T		H		2.25		
FW99/43	9	M2	FANS	S	S		T		H		1.25		
FW99/44	9	M2	FANS	S	S		T		H		0.95		
FW99/45	9	M2	FANS	S	S		T		L		1.97		
FW99/46	9	M2	FANS	S	S		T		L		1.45		
FW99/47	9	M2	FANS	S	S		T		L		1.95		
FW99/48	9	M2	FANS	S	S		T		L		1.17		
FW99/49	9	M2	FANS	S	S		T		L		1.56		
FW99/50	9	M2	FANS	S	S		T		L		1.45		
FW99/51	9	M2	FANS	S	S		T		L		1.89		
FW99/52	9	M2	FANS	S	S		T		L		1.35		
FW99/53	9	E	FANS	S							0.95		
FW99/54	9	E	FANS	S							1.10		
FW99/55	9	E	FANS	S							2.10		
FW99/56	9	E	FANS	S							1.15		
FW99/57	9	E	FANS	S	S					H	1.65		
FW99/58	9	E	FANS	S	S					H	1.30		
FW99/59	9	E	FANS	S	S					H	1.10		
FW99/60	9	E	FANS	S	S					H	1.18		
MW99/01	9	B	Markle	S							1.37		
MW99/02	9	B	Markle	S							0.98		
MW99/03	9	B	Markle	S							1.65		
MW99/04	9	B	Markle	S							1.82		
MW99/05	9	M1	Markle	S							0.95		
MW99/06	9	M1	Markle	S							1.83		
MW99/07	9	M1	Markle	S							2.94		
MW99/08	9	M1	Markle	S							1.45		
MW99/09	9	M1	Markle	S			T				0.98		
MW99/10	9	M1	Markle	S			T				1.10		
MW99/11	9	M1	Markle	S			T				1.50		
MW99/12	9	M1	Markle	S			T				1.47		
MW99/13	9	M2	Markle	S							0.97		
MW99/14	9	M2	Markle	S							1.19		
MW99/15	9	M2	Markle	S							1.35		
MW99/16	9	M2	Markle	S							1.05		
MW99/17	9	M2	Markle	S	S		T		L		1.95		
MW99/18	9	M2	Markle	S	S		T		L		0.95		
MW99/19	9	M2	Markle	S	S		T		L		0.84		
MW99/20	9	M2	Markle	S	S		T		L		0.85		
MW99/21	9	E	Markle	S							1.10		
MW99/22	9	E	Markle	S							1.37		
MW99/23	9	E	Markle	S							0.85		
MW99/24	9	E	Markle	S							1.23		
MW99/25	9	E	Markle	S	S		T		L	H	2.10		
MW99/26	9	E	Markle	S	S		T		L	H	0.85		
MW99/27	9	E	Markle	S	S		T		L	H	1.36		
MW99/28	9	E	Markle	S	S		T		L	H	1.20		

BW99/01	9	B	Biel Grange	S							3.25		
BW99/02	9	B	Biel Grange	S							0.94		
BW99/03	9	B	Biel Grange	S							1.50		
BW99/04	9	B	Biel Grange	S							2.27		
BW99/05	9	M1	Biel Grange	S							1.89		
BW99/06	9	M1	Biel Grange	S							0.79		
BW99/07	9	M1	Biel Grange	S							1.23		
BW99/08	9	M1	Biel Grange	S							1.95		
BW99/09	9	M1	Biel Grange	S			T				2.17		
BW99/10	9	M1	Biel Grange	S			T				2.87		
BW99/11	9	M1	Biel Grange	S			T				1.58		
BW99/12	9	M1	Biel Grange	S			T				1.24		
BW99/13	9	M1	Biel Grange	S			T				1.47		
BW99/14	9	M1	Biel Grange	S			T				1.63		
BW99/15	9	M1	Biel Grange	S			T				2.14		
BW99/16	9	M1	Biel Grange	S			T				2.48		
BW99/17	9	M1	Biel Grange	S			T				0.87		
BW99/18	9	M1	Biel Grange	S			T				1.21		
BW99/19	9	M1	Biel Grange	S			T				1.64		
BW99/20	9	M1	Biel Grange	S			T				1.65		
BW99/21	9	M1	Biel Grange	S			T				1.08		
BW99/22	9	M1	Biel Grange	S			T				1.22		
BW99/23	9	M1	Biel Grange	S			T				2		
BW99/24	9	M1	Biel Grange	S			T				1.17		
BW99/25	9	M2	Biel Grange	S							2.15		
BW99/26	9	M2	Biel Grange	S							1.52		
BW99/27	9	M2	Biel Grange	S							1.45		
BW99/28	9	M2	Biel Grange	S							1.24		
BW99/29	9	M2	Biel Grange	S	S		T		H		1.05		
BW99/30	9	M2	Biel Grange	S	S		T		H		1.65		
BW99/31	9	M2	Biel Grange	S	S		T		H		2.1		
BW99/32	9	M2	Biel Grange	S	S		T		H		2		
BW99/33	9	M2	Biel Grange	S	S		T		L		0.94		
BW99/34	9	M2	Biel Grange	S	S		T		L		1.42		
BW99/35	9	M2	Biel Grange	S	S		T		L		1.56		
BW99/36	9	M2	Biel Grange	S	S		T		L		1.16		
BW99/37	9	M2	Biel Grange	S	S		T		L		2.1		
BW99/38	9	M2	Biel Grange	S	S		T		L		5.47		
BW99/39	9	M2	Biel Grange	S	S		T		L		0.69		
BW99/40	9	M2	Biel Grange	S	S		T		L		1.89		
BW99/41	9	M2	Biel Grange	S	S		T		H		1.87		
BW99/42	9	M2	Biel Grange	S	S		T		H		2.1		
BW99/43	9	M2	Biel Grange	S	S		T		H		2.18		
BW99/44	9	M2	Biel Grange	S	S		T		H		1.58		
BW99/45	9	E	Biel Grange	S							3.74		
BW99/46	9	E	Biel Grange	S							2.25		
BW99/47	9	E	Biel Grange	S							0.74		
BW99/48	9	E	Biel Grange	S							1.53		
BW99/49	9	E	Biel Grange	S	S		T		H	H	1.57		
BW99/50	9	E	Biel Grange	S	S		T		H	H	2.2		
BW99/51	9	E	Biel Grange	S	S		T		H	H	1.95		
BW99/52	9	E	Biel Grange	S	S		T		H	H	1.45		

BW99/53	9	E	Biel Grange	S	S		T		L	H	1.65		
BW99/54	9	E	Biel Grange	S	S		T		L	H	0.95		
BW99/55	9	E	Biel Grange	S	S		T		L	H	1.35		
BW99/56	9	E	Biel Grange	S	S		T		L	H	1.78		
B2W99/01	9	B	Biel Grange	S							1.21		
B2W99/02	9	B	Biel Grange	S							2		
B2W99/03	9	B	Biel Grange	S							1.07		
B2W99/04	9	B	Biel Grange	S							1.22		
B2W99/05	9	M1	Biel Grange	S							2.12		
B2W99/06	9	M1	Biel Grange	S							0.73		
B2W99/07	9	M1	Biel Grange	S							0.99		
B2W99/08	9	M1	Biel Grange	S							3.21		
B2W99/09	9	M1	Biel Grange	S			T				1.94		
B2W99/10	9	M1	Biel Grange	S			T				0.73		
B2W99/11	9	M1	Biel Grange	S			T				1.37		
B2W99/12	9	M1	Biel Grange	S			T				1.94		
B2W99/13	9	M1	Biel Grange	S			T				1.82		
B2W99/14	9	M1	Biel Grange	S			T				0.72		
B2W99/15	9	M1	Biel Grange	S			T				1.21		
B2W99/16	9	M1	Biel Grange	S			T				1.68		
B2W99/17	9	M1	Biel Grange	S			T				0.99		
B2W99/18	9	M1	Biel Grange	S			T				1.45		
B2W99/19	9	M1	Biel Grange	S			T				1.32		
B2W99/20	9	M1	Biel Grange	S			T				1.89		
B2W99/21	9	M2	Biel Grange	S							1.65		
B2W99/22	9	M2	Biel Grange	S							1.85		
B2W99/23	9	M2	Biel Grange	S							3.45		
B2W99/24	9	M2	Biel Grange	S							0.86		
B2W99/25	9	M2	Biel Grange	S	S		T		H		1.08		
B2W99/26	9	M2	Biel Grange	S	S		T		H		2.35		
B2W99/27	9	M2	Biel Grange	S	S		T		H		1.21		
B2W99/28	9	M2	Biel Grange	S	S		T		H		2		
B2W99/29	9	M2	Biel Grange	S	S		T		H		2.16		
B2W99/30	9	M2	Biel Grange	S	S		T		H		2.49		
B2W99/31	9	M2	Biel Grange	S	S		T		H		1.5		
B2W99/32	9	M2	Biel Grange	S	S		T		H		1.47		
B2W99/33	9	M2	Biel Grange	S	S		T		H		1.55		
B2W99/34	9	M2	Biel Grange	S	S		T		H		1.68		
B2W99/35	9	M2	Biel Grange	S	S		T		H		0.82		
B2W99/36	9	M2	Biel Grange	S	S		T		H		1.19		
B2W99/37	9	E	Biel Grange	S							1.85		
B2W99/38	9	E	Biel Grange	S							0.85		
B2W99/39	9	E	Biel Grange	S							1.32		
B2W99/40	9	E	Biel Grange	S							2.35		
B2W99/41	9	E	Biel Grange	S	S		T		H	H	1.25		
B2W99/42	9	E	Biel Grange	S	S		T		H	H	2.04		
B2W99/43	9	E	Biel Grange	S	S		T		H	H	1.98		
B2W99/44	9	E	Biel Grange	S	S		T		H	H	1.54		

Key

Year 8 = 1998, 9 = 1999.

Sampling time	B = Before start of spray programme; M = Before end of spray programme E = After end of spray programme; s = seedling trap plants
Geographical location	E = England; S = Scotland
Strobilurin	S = Strobilurin; O = Other; blank = Untreated M = Morpholine; T = DMI
Doses	L = low dose, < half rate; H = high dose rate, half rate or above.

APPENDIX 4

Barley mildew isolate details

									Fungicide treatment **prior to sampling**			RF		
Isolate code	Year	Sampling time	Trial identification	Geographic location	Strobilurin?	if strobilurin, +/- morpholine	if strobilurin, +/- DMI	if strobilurin +/- quinoxyfen	Strobilurin timing and dose			azoxystrobin	morpholine	DMI
									GS31	GS37/39	later			
HH T1	8	E	H. Hall	E								1.03	3.96	10.18
HH T2	8	E	H. Hall	E	O							0.47	7.59	7.43
HH T4	8	E	H. Hall	E	S		T		H		H	1.82	5.97	7.98
HH T6	8	E	H. Hall	E	S	M			H		H	1.12	11.82	7.53
HH T7	8	E	H. Hall	E	S	M	T		H			0.87	25.70	10.63
SH T1	8	E	Seale Hayne	E								1.67	4.21	21.26
SH T2	8	E	Seale Hayne	E	O							0.76	3.53	16.31
HA T1	8	E	H. Adams	E								1.19	4.59	24.75
HA T6	8	E	H. Adams	E	S	M			H		H	1.28	9.00	25.28
WYE S	8	E	Wye	E	S	M			H		H	0.94	6.89	23.92
MOR T6	8	E	Morley	E	S	M			H		H	1.52	11.02	33.05
CP T1	8	E	Cockle Park	E								1.19	4.81	23.66
RR99/1	9	B	Morley	E								0.90		
RR99/2	9	B	Morley	E								0.46		
RR99/3	9	B	Morley	E								0.93		
RR99/4	9	B	H. Adams	E								1.11		
RR99/5	9	B	H. Adams	E								0.56		
RR99/7	9	B	H. Hall	E								0.84		
RR99/8	9	B	H. Hall	E								0.65		
RR99/9	9	B	H. Hall	E								0.39		
RR99/10	9	B	H. Hall	E								1.37		
RR99/11	9	B	Bridgets	E								1.67		
RR99/12	9	B	Bridgets	E								1.51		
RR99/13	9	B	Bridgets	E								1.37		
RR99/14	9	B	Bridgets	E								0.43		
RR99/15	9	B	Bridgets	E								2.23		
RR99/16	9	B	Bridgets	E								0.77		
RR99/17	9	B	Bridgets	E								0.99		
RR99/18	9	B	Bridgets	E								0.42		
RR99/19	9	B	Bridgets	E								0.80		
RR99/20	9	E	H. Adams	E	O							0.35		
RR99/32	9	E	Gwent	E	O							0.63		
RR99/33	9	E	Gwent	E	O							1.71		
RR99/34	9	E	Gwent	E	O							6.09		
RR99/36	9	E	Gwent	E	O							0.54		
RR99/37	9	E	Gwent	E	S	M			H		H	1.76		

RR99/38	9	E	Gwent	E	S	M			H		H	0.37		
RR99/43	9	E	Wye	E	O							0.58		
RR99/45	9	E	Wye	E	S	M		Q	H		H	0.79		
RR99/46	9	E	Wye	E	S	M		Q	H		H	1.56		
RR99/47	9	E	Wye	E	S	M		Q	H		H	1.83		
RR99/48	9	E	Wye	E	S	M		Q	H		H	0.99		
RR99/49	9	E	Bridgets	E	S		T		H		H	2.14		
RR99/51	9	E	Bridgets	E	O							2.06		
RR99/53	9	E	Bridgets	E	O							0.26		
RR99/54	9	E	Bridgets	E	O							1.02		
RR99/55	9	E	Bridgets	E	S	M			H		H	2.98		
RR99/56	9	E	Bridgets	E	S		T		H		H	1.89		
RR99/57	9	E	Bridgets	E	S	M			H		H	2.12		
RR99/58	9	E	Bridgets	E	S	M	T		H		H	2.88		
RR99/59	9	E	Bridgets	E	O							2.37		
RR99/61	9	E	Bridgets	E	O							0.64		
RR99/79	9	E	H. Hall	E	O							1.12		
RR99/81	9	E	H. Hall	E	O							2.72		
RR99/82	9	E	H. Hall	E	S	M			H		H	1.49		
RR99/83	9	E	H. Hall	E	O							1.00		
RR99/84	9	E	H. Adams	E	O							0.93		
RR99/85	9	E	H. Adams	E	S		T		H		H	1.45		
RR99/86	9	E	H. Adams	E	O							1.11		
RR99/87	9	E	H. Adams	E	S	M			H		H	1.76		
RR99/88	9	E	H. Adams	E	S		T		H		H	1.03		
RR99/89	9	E	H. Adams	E	S	M			H		H	0.84		
RR99/90	9	E	H. Adams	E	O							1.15		
RR99/91	9	E	H. Adams	E	O							1.33		
RR99/92	9	E	H. Adams	E	O							1.36		
RR99/93	9	E	H. Adams	E	S	M			H		H	1.63		
RR99/94	9	E	H. Adams	E	S		T		H		H	0.71		
RR99/96	9	s	Hilton	E	S				L			1.78		
RR99/99	9	E	Morley	E	O							3.54		
RR99/104	9	E	H. Adams	E	O							1.13		
RR99/106	9	E	H. Adams	E	O							2.73		
RR99/108	9	E	H. Adams	E	S	M			H		H	0.95		
RR99/111	9	E	H. Adams	E	S	M			H		H	2.54		
BB98/01	8	B	BUSH	S								3.2	11.7	10.7
BB98/02	8	B	BUSH	S								2.7	9.7	30.6
BB98/03	8	B	BUSH	S								1.0	4.3	22.6
BB98/04	8	B	BUSH	S								1.4	2.8	12.9
BB98/05	8	M	BUSH	S								1.7	13.4	29.6
BB98/06	8	M	BUSH	S								1.7	14.6	23.8
BB98/07	8	M	BUSH	S								1.6	10.8	29.4
BB98/08	8	M	BUSH	S								2.0	12.6	14.5
BB98/09	8	M	BUSH	S	O							0.8	15.4	24.6
BB98/10	8	M	BUSH	S	O							1.5	12.8	12.4
BB98/11	8	M	BUSH	S	O							2.0	11.7	18.9
BB98/12	8	M	BUSH	S	O							1.8	9.8	12.4
BB98/13	8	M	BUSH	S	S		T		H	H		1.56	3.62	25.6
BB98/14	8	M	BUSH	S	S		T		H	H		1.98	12.4	22.4
BB98/15	8	M	BUSH	S	S		T		H	H		0.95	11.5	40.7

BB98/16	8	M	BUSH	S	S		T		H	H		1.1	16.9	10.3
BB98/17	8	M	BUSH	S	S	M			L	L		2.16	8.4	40.8
BB98/18	8	M	BUSH	S	S	M			L	L		1.44	3.2	44.6
BB98/19	8	M	BUSH	S	S	M			L	L		3.1	2.5	10.5
BB98/20	8	M	BUSH	S	S	M			L	L		1.25	6.3	39.6
BB98/21	8	M	BUSH	S	S	M			L	L		1.37	10.5	15.7
BB98/22	8	M	BUSH	S	S	M			L	L		4.05	14.3	26.2
BB98/23	8	M	BUSH	S	S	M			L	L		2.1	4.7	8.1
BB98/24	8	M	BUSH	S	S	M			L	L		0.99	15.7	19.6
BB98/25	8	M	BUSH	S	O							1.15	11.5	8.7
BB98/26	8	M	BUSH	S	O							2.86	10.7	15.6
BB98/27	8	M	BUSH	S	O							1.97	17.6	27.3
BB98/28	8	M	BUSH	S	O							1.86	15.4	20.8
BB98/29	8	M	BUSH	S	O							1.5	12.6	13.5
BB98/30	8	M	BUSH	S	O							0.94	2.86	39.4
BB98/31	8	M	BUSH	S	O							2	9.82	45.8
BB98/32	8	M	BUSH	S	O							1.87	10.9	26.3
BB98/33	8	E	BUSH	S								1.42	8.75	34.5
BB98/34	8	E	BUSH	S								1.66	6.93	25.6
BB98/35	8	E	BUSH	S								1.51	7.36	32.1
BB98/36	8	E	BUSH	S								1.67	3.24	9.64
BB98/37	8	E	BUSH	S	O							0.79	6.59	35.6
BB98/38	8	E	BUSH	S	O							2.1	15.7	30.2
BB98/39	8	E	BUSH	S	O							0.32	12.8	25.4
BB98/40	8	E	BUSH	S	O							1.98	11.4	19.1
BB98/41	8	E	BUSH	S	S		T		H	H		0.72	3.6	17.6
BB98/42	8	E	BUSH	S	S		T		H	H		2.13	9.78	25.1
BB98/43	8	E	BUSH	S	S		T		H	H		2.55	2.13	15.8
BB98/44	8	E	BUSH	S	S		T		H	H		2.18	16.6	27.3
BB98/45	8	E	BUSH	S	S	M			L	L		2.29	17.1	22.6
BB98/46	8	E	BUSH	S	S	M			L	L		1.01	19.2	24.7
BB98/47	8	E	BUSH	S	S	M			L	L		1.41	15.3	12.4
BB98/48	8	E	BUSH	S	S	M			L	L		1.15	11.9	40.1
BB98/49	8	E	BUSH	S	S	M			L	L		0.61	12.9	8.1
BB98/50	8	E	BUSH	S	S	M			L	L		1.96	24.2	15.6
BB98/51	8	E	BUSH	S	S	M			L	L		2.15	3.8	20.5
BB98/52	8	E	BUSH	S	S	M			L	L		2.13	11.5	23.6
BB98/53	8	E	BUSH	S	O							2.55	15.4	25.7
BB98/54	8	E	BUSH	S	O							1.61	10.7	31.7
BB98/55	8	E	BUSH	S	O							1.58	11.1	36.4
BB98/56	8	E	BUSH	S	O							3.7	20.2	35.3
BB98/57	8	E	BUSH	S	O							1.75	16.5	33.1
BB98/58	8	E	BUSH	S	O							0.94	10.8	38.2
BB98/59	8	E	BUSH	S	O							3.25	22.3	31.4
BB98/60	8	E	BUSH	S	O							2.1	12.8	37.2
BB99/01	9	B	BUSH	S								4.1		
BB99/02	9	B	BUSH	S								0.95		
BB99/03	9	B	BUSH	S								2.38		
BB99/04	9	B	BUSH	S								1.37		
BB99/05	9	M	BUSH	S								2.68		
BB99/06	9	M	BUSH	S								3.41		
BB99/07	9	M	BUSH	S								2.87		

BB99/08	9	M	BUSH	S								0.72		
BB99/09	9	M	BUSH	S	O		T					0.53		
BB99/10	9	M	BUSH	S	O		T					2.78		
BB99/11	9	M	BUSH	S	O		T					1.35		
BB99/12	9	M	BUSH	S	O		T					1.94		
BB99/13	9	M	BUSH	S	S	M			L			1.81		
BB99/14	9	M	BUSH	S	S	M			L			2.24		
BB99/15	9	M	BUSH	S	S	M			L			1.83		
BB99/16	9	M	BUSH	S	S	M			L			4.35		
BB99/13	9	M	BUSH	S	S	M			H			2.49		
BB99/14	9	M	BUSH	S	S	M			H			4.37		
BB99/15	9	M	BUSH	S	S	M			H			2.56		
BB99/16	9	M	BUSH	S	S	M			H			3.1		
BB99/13	9	E	BUSH	S								1.75		
BB99/14	9	E	BUSH	S								1.25		
BB99/15	9	E	BUSH	S								1.48		
BB99/16	9	E	BUSH	S								1.37		
BB299/01	9	B	BUSH	S								2.73		
BB299/02	9	B	BUSH	S								0.87		
BB299/03	9	B	BUSH	S								1.25		
BB299/04	9	B	BUSH	S								1.98		
BB299/05	9	M	BUSH	S								1.37		
BB299/06	9	M	BUSH	S								2.23		
BB299/07	9	M	BUSH	S								1.45		
BB299/08	9	M	BUSH	S								1.34		
BB299/09	9	M	BUSH	S								1.95		
BB299/10	9	M	BUSH	S								0.96		
BB299/11	9	M	BUSH	S								2.1		
BB299/12	9	M	BUSH	S								3.1		
BB299/13	9	M	BUSH	S	S		T		H			1.38		
BB299/14	9	M	BUSH	S	S		T		H			2.37		
BB299/15	9	M	BUSH	S	S		T		H			2.65		
BB299/16	9	M	BUSH	S	S		T		H			4.91		
BB299/17	9	M	BUSH	S	O							0.85		
BB299/18	9	M	BUSH	S	O							1.72		
BB299/19	9	M	BUSH	S	O							1.98		
BB299/20	9	M	BUSH	S	O							0.72		
BB299/21	9	E	BUSH	S	S		T			H		2.63		
BB299/22	9	E	BUSH	S	S		T			H		3.32		
BB299/23	9	E	BUSH	S	S		T			H		1.58		
BB299/24	9	E	BUSH	S	S		T			H		3.1		
BF99/01	9	B	FANS	S								0.99		
BF99/02	9	B	FANS	S								1.45		
BF99/03	9	B	FANS	S								0.73		
BF99/04	9	B	FANS	S								1.99		
BF99/05	9	M	FANS	S								4.55		
BF99/06	9	M	FANS	S								0.84		
BF99/07	9	M	FANS	S								0.96		
BF99/08	9	M	FANS	S								0.83		
BF99/09	9	M	FANS	S	O							1.25		
BF99/10	9	M	FANS	S	O							0.89		
BF99/11	9	M	FANS	S	O							2.11		

BF99/12	9	M	FANS	S	O							0.92		
BF99/13	9	E	FANS	S								1.23		
BF99/14	9	E	FANS	S								1.18		
BF99/15	9	E	FANS	S								1.58		
BF99/16	9	E	FANS	S								2.75		
BF299/01	9	B	FANS	S								2.61		
BF299/02	9	B	FANS	S								1.69		
BF299/03	9	B	FANS	S								1.75		
BF299/04	9	B	FANS	S								2.27		
BF299/05	9	M	FANS	S								2.23		
BF299/06	9	M	FANS	S								3.39		
BF299/07	9	M	FANS	S								1.91		
BF299/08	9	M	FANS	S								1.95		
BF299/09	9	M	FANS	S	S	M		Q	L			0.98		
BF299/10	9	M	FANS	S	S	M		Q	L			1.15		
BF299/11	9	M	FANS	S	S	M		Q	L			1.67		
BF299/12	9	M	FANS	S	S	M		Q	L			1.34		
BF299/13	9	E	FANS	S								2.1		
BF299/14	9	E	FANS	S								0.87		
BF299/15	9	E	FANS	S								2.64		
BF299/16	9	E	FANS	S								1.94		
BGB99/01	9	B	Biel Grange	S								1.15		
BGB99/02	9	B	Biel Grange	S								1.56		
BGB99/03	9	B	Biel Grange	S								3.97		
BGB99/04	9	B	Biel Grange	S								2.58		
BGB99/05	9	M	Biel Grange	S								1.39		
BGB99/06	9	M	Biel Grange	S								1.75		
BGB99/07	9	M	Biel Grange	S								1.15		
BGB99/08	9	M	Biel Grange	S								0.89		
BGB99/09	9	M	Biel Grange	S	S	M			H			3.1		
BGB99/10	9	M	Biel Grange	S	S	M			H			2.87		
BGB99/11	9	M	Biel Grange	S	S	M			H			3.58		
BGB99/12	9	M	Biel Grange	S	S	M			H			2.19		
BGB99/13	9	M	Biel Grange	S	O							0.98		
BGB99/14	9	M	Biel Grange	S	O							1.15		
BGB99/15	9	M	Biel Grange	S	O							2.25		
BGB99/16	9	M	Biel Grange	S	O							2.98		
BGB99/17	9	M	Biel Grange	S	S				L	L		0.91		
BGB99/18	9	M	Biel Grange	S	S				L	L		0.85		
BGB99/19	9	M	Biel Grange	S	S				L	L		0.83		
BGB99/20	9	M	Biel Grange	S	S				L	L		1.25		
BGB99/21	9	M	Biel Grange	S	S				H	H		1.25		
BGB99/22	9	M	Biel Grange	S	S				H	H		3.05		
BGB99/23	9	M	Biel Grange	S	S				H	H		0.95		
BGB99/24	9	M	Biel Grange	S	S				H	H		2.63		
BGB99/25	9	M	Biel Grange	S	S				H	H		1.56		
BGB99/26	9	M	Biel Grange	S	S				H	H		1.25		
BGB99/27	9	M	Biel Grange	S	S				H	H		1.64		
BGB99/28	9	M	Biel Grange	S	S				H	H		0.95		
BGB99/25	9	E	Biel Grange	S	S				L	L	L	1.57		
BGB99/26	9	E	Biel Grange	S	S				L	L	L	2.1		
BGB99/27	9	E	Biel Grange	S	S				L	L	L	0.96		

BGB99/28	9	E	Biel Grange	S	S				L	L	L	1.68		

Key

Year	8 = 1998, 9 = 1999.
Sampling time	B = Before start of spray programme; M = Before end of spray programme
	E = After end of spray programme; s = seedling trap plants
Geographical location	E = England; S = Scotland
Strobilurin	S = Strobilurin; O = Other; blank = Untreated
	M = Morpholine; T = DMI; Q = Quinoxyfen
Doses	L = low dose, < half rate; H = high dose rate, half rate or above.

APPENDIX 5

Wheat yellow rust isolate details

Isolate code	Year	Sampling time	Trial identification	Geographic location	Strobilurin?	if strobilurin, +/- morpholine	if strobilurin, +/- DMI	Fungicide treatment **prior to sampling** Strobilurin timing and dose GS31	GS37/39	later	RF azoxystrobin
98/1	8	M	L. Sutton	E							0.20
98/2	8	M	L. Sutton	E	O						4.14
98/3	8	M	L. Sutton	E	O						2.12
98/6	8	M	L. Sutton	E							3.88
98/7	8	M	L. Sutton	E							2.12
98/8	8	M	L. Sutton	E	S		T		L		1.33
98/9	8	M	L. Sutton	E	S		T		H		0.57
98/10	8	M	L. Sutton	E	O						2.66
98/11	8	M	L. Sutton	E	S		T		H		1.21
98/12	8	M	L. Sutton	E	S		T		H		2.95
98/13	8	M	L. Sutton	E	S		T		H		1.18
98/14	8	M	L. Sutton	E	S		T	L	H		0.04
98/15	8	M	L. Sutton	E	S		T	L	L		2.43
98/16	8	M	L. Sutton	E	S			L	L		2.92
98/17	8	M	L. Sutton	E	S		T	L	L		4.65
98/18	8	M	L. Sutton	E	O						3.53
98/19	8	M	L. Sutton	E	S		T		H		1.13
98/21	8	E	B. Butlins	E							1.16
98/23	8	E	B. Butlins	E	S			H	H		1.55
98/31	8	E	Upton	E							1.47
98/32	8	E	Upton	E	S			L	H	H	0.97
98/34	8	E	Upton	E	S	M	T			H	1.87
98/36	8	E	Upton	E							1.49
98/37	8	E	Upton	E	S	M		H	L		1.30
99/19	9	E	Morley	E	S	M	T		L	L	0.60
99/22	9	E	Morley	E	S		T		H	H	0.65
99/26	9	E	Morley	E	S	M	T		H	H	1.47
99/30	9	E	Cambridge	E	S	M	T		H	H	0.01
99/31	9	E	Cambridge	E	S	M	T		H	H	0.99
99/32	9	E	Cambridge	E	S	M	T		H	H	0.32
99/33	9	E	Cambridge	E	S	M	T		L	L	0.91
99/34	9	E	Cambridge	E	S	M	T		L	L	1.65
99/35	9	E	Cambridge	E	S	M	T		L	L	2.10

Key

Year	8 = 1998, 9 = 1999.
Sampling time	B = Before start of spray programme; M = Before end of spray programme
	E = After end of spray programme
Geographical location	E = England; S = Scotland
Strobilurin	S = Strobilurin; O = Other; blank = Untreated
	M = Morpholine; T = DMI
Doses	L = low dose, < half rate; H = high dose rate, half rate or above.