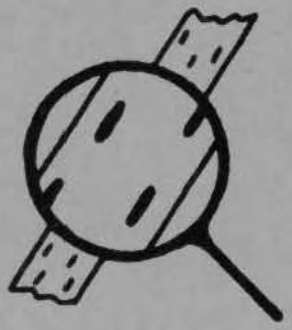
U.K. CEREAL PATHOGEN VIRULENCE SURVEY



1986 Annual Report

UNITED KINGDOM CEREAL PATHOGEN VIRULENCE SURVEY

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THE UNITED KINGDOM CEREAL PATHOGEN VIRULENCE SURVEY

The Survey, formerly the Physiologic Race Survey of Cereal Pathogens, commenced in 1967 following an unexpected epidemic of wheat yellow rust (*Puccinia striiformis*) which caused severe yield losses in the widely grown cultivar Rothwell Perdix. The epidemic was the result of the development of increased virulence for this previously resistant cultivar.

The Survey is supported financially by the Ministry of Agriculture, Fisheries and Food and the Agricultural Research Council.

OBJECTIVES

The principal objective is the early detection of increased virulence compatible with those resistances currently being exploited in commercial cultivars and breeding programmes.

Secondary objectives include providing information for cultivar diversification schemes, monitoring the frequency of virulences and virulence combinations, measuring the effect of changes in cultivar on the pathogen population and detecting fungicide insensitivity in some pathogens.

METHODS

The Survey is carried out annually. In April, a list of cereal cultivars from which disease samples are requested is sent to about 100 pathologists and agronomists within the United Kingdom, who collect samples of infected leaves from field crops and cultivar trials and send them by post to the three testing centres:

- National Institute of Agricultural Botany, Cambridge for yellow rust of wheat and barley.

- Plant Breeding Institute, Cambridge for mildew of wheat and barley.

- Welsh Plant Breeding Station, Aberystwyth, for brown rust of wheat and barley, mildew and crown rust of oats and Rhynchosporium and net blotch of barley.

Other sampling methods are also used including mobile nurseries and the wind impaction spore trap.

At each centre, virulence is measured by inoculating seedlings and/or adult plants with spores multiplied from the disease samples.

Seedling tests are usually carried out under controlled environment conditions. Adult plant tests are carried out in the field, in Polythene tunnels or in controlled environment rooms.

RESULTS

The United Kingdom Cereal Pathogen Virulence Survey Committee meets annually to discuss the scientific and agricultural significance of the results of virulence tests carried out during the previous year. The results are used to place winter wheat and spring barley cultivars in diversification groups on the basis of their specific resistances. The results of the virulence tests and the diversification schemes are published shortly afterwards in the Annual Report.

The information provided by the Survey is used in various ways. Isolates possessing new virulences are used by the National Institute of Agricultural Botany to evaluate the resistance of cereal cultivars in trial in England and Wales. These isolates are also used by plant breeders to select lines with effective forms of resistance. Isolates are also supplied to Universities and Colleges for research projects and teaching purposes. Versions of the cultivar diversification schemes, modified to meet regional requirements, are published in the National Institute of Agricultural Botany Farmers Leaflet No. 8 'Recommended varieties of cereals', the Scottish Agricultural Colleges leaflet 'Recommended varieties of cereals', and by the Agricultural Development & Advisory Service.

EXPLANATION OF TERMS USED TO DESCRIBE RESISTANCE AND VIRULENCE IN THIS REPORT

Specific resistances and specific virulences

Resistance is the ability of a host cultivar to defend itself against infection by a pathogen isolate. Conversely, virulence is the ability of a pathogen isolate to infect a host cultivar.

Some cultivars possess resistance that is more effective against some isolates than others and this is termed 'specific' resistance. Similarly, some isolates are more able to infect some cultivars than others and this is termed 'specific' virulence.

The terms 'specific resistance factor' and 'specific virulence factor' are used to describe unidentified genes in host and pathogen which interact with one another. Specific resistance factors are numbered R1, R2 ... Rn and specific virulences are number V1, V2 ... Vn. Each individual specific resistance factor is effective against all isolates except those possessing the corresponding virulence factor. Hence a cultivar possessing R4 has effective resistance against all isolates except those possessing V4. Cultivars lacking specific resistances are classified as R0 and isolates lacking specific virulences are classified as V0.

Specific resistances and virulences relating to particular cereal diseases are described by additional prefixes for crop (W = wheat, B = barley and O = oats) and disease M = mildew, Y = yellow rust, B = brown rust, C = crown rust, R = Rhynchosporium), hence WYR 2 and BMV 5.

Terms describing resistance at different growth stages

Resistances may also be classified according to the growth stages at which they are effective:

- overall resistances
  are effective at all growth stages

- seedling resistances
  are effective at seedling growth stages but ineffective at adult plant growth stages

- adult plant resistances
  are effective at adult plant growth stages but ineffective at seedling growth stages

SUMMARY OF RESULTS FOR 1986

Mildew of Wheat

The resistances of several new cultivars were found to be similar to those of other cultivars with known resistance characters. Levels of adult plant background resistance were quantified using both adult plant and seedling scores from the field. Indirect tests showed that occurrence of single colony isolates with low to moderate levels of insensitivity to the triazole fungicides was independent of treatment of trap seedlings.

Yellow Rust of Wheat

The frequency of WYV6 remained very high in 1986 samples and there were substantial increases in the frequencies of WYV4 and the combination WYV1,4. Isolates in which WYV1,4 was combined with the adult plant virulence WYV13 were identified for the first time.

Brown Rust of Wheat

Seedling tests indicated that the spring wheat cultivars Jerico, Wembley and Solitaire have a temperature sensitive resistance. Adult plant field tests identified several new winter and spring wheat cultivars with effective resistance to the two isolates tested in 1986.

Mildew of barley

Pathogenicity for cultivars with resistance derived from cv. Rupee was found for the first time in the field, in addition to a low degree of pathogenicity for cv Atem. A low level of insensitivity to fenpropimorph was also identified.

The use of combinations of resistance characters in new cultivars and of fungicides in mixtures has caused rapid selection, respectively, for combinations of pathogenicity characters and of fungicide insensitivity characters.

The main feature in Northern Ireland was the almost total lack of mildew, but those samples that were obtained had generally increased pathogenicity values over previous year.

Yellow Rust of Barley

The incidence of yellow rust of barley was extremely low in 1986 and no samples were received by the Survey.

Brown Rust of Barley

Two new virulence combinations, Octal 1657 and 1677, were detected in the seedling tests. BRV-3 had not previously been found in combination with the Triumph virulence, BRV-10. The winter barley cultivar Medallion again expressed its high level of resistance in adult plant tests in field isolation nurseries as did the spring cultivars Simon (BRR-3) and Corniche (BRR-?).

Rhynchosporium of Barley

Virulence to cultivars Pipkin (BRR-5) and Osiris (BRR-6) was not detected, whilst the resistance of cultivar Digger remained effective to all isolates. Field isolation nurseries confirmed virulence to cultivar Osiris in isolate Rs-85-50. The Rhynchosporium survey has contributed to a joint project between Ciba-Geigy and Long Ashton Research Station to evaluate fungicide insensitivity.

Net Blotch of Barley

In seedling tests the spring cultivars C.I. 5401, C.I. 9820, C.I. 4795, C.I. 4502 and C.I. 9214 gave low frequencies of corresponding virulences confirming their value for inclusion in breeding programmes. The winter cultivars Code 65 and Marinka were also resistant to all isolates. The East German spring cultivars Corniche and Triumph appeared to be more susceptible to the spotting isolate in field isolation nurseries and this requires careful monitoring.

Mildew of Oats

As in recent years, race 5 (OMV 1,2,3) was the predominant virulence combination. Race 3 (OMV 1,2) maintained a frequency level of 30%, whilst one isolate overcame the Avena barbata (OMR 4) resistance. Adult plant tests using detached leaves failed to indicate adaptation to adult plant resistance types in any of the mildew populations sampled.

Crown Rust of Oats

Only one sample of crown rust was received and this was identified as race 251, which occurs commonly in the UK.

MILDEW OF WHEAT

Thea M.C. van Kints

Plant Breeding Institute, Cambridge

Mean pathogenicity values were similar to those of previous years, but data in this report indicate that changes are expected. Isolates from WMR7 cultivars were more pathogenic on WMR2 cultivars than isolates from WMR2 cultivars. Data from the field revealed adult plant background resistance of cv. Fenman and intermediate seedling and adult plant resistance of cv. Brock. Cv. Tonic has at least some resistance characters in common with cv. Broom, as do cvs. Wembley and Solitaire with cv. Anfield, and cv. Dauntless with WMR7 cultivars. A static roof nursery was more suitable than the wind impaction spore trap for obtaining direct colony counts on differentials.

Insensitivity to the triazole fungicides did not remain constant unlike in 1985. Indirect tests showed that occurrence of single colony isolates with low to moderate levels of insensitivity was independent of treatment of trap seedlings.

Table 1. Wheat mildew resistance (WMR) group definitions, differential cultivars and identified resistance genes

WMR group	Gene	Cultivar
0	-	Cerco, Moulin, Jerico+, Minaret+, Alexandria+
1	Pm 1	Anfield
2	Pm 2	Galahad+, Longbow+, Fenman, Norman+, Avalon+
3	Pm 3a, 3b, 3c	Asosan, Chul, Sonora
4	Pm 4a, 4b	Khapli, Armada
5	Pm 5	Hope
6	Pm 6	Timgalen
-	Pm 7	Transec
7	Pm 8	Ambassador, Corinthian
8	Mli *	Aquila, Mercia+
9	Pm 2 + Mld*	Maris Dove
2+4		Sappo
2+6		Brimstone+, Gawain
2+7		Hornet+
4+8		Mission
2+4+6		Rendezvous+
2+6+7		CWW 1645/5
2+6+8		Parade+
2+ Talent		Brock+
7+ ?		Slejpner+, Dauntless
5+8+ ?		Broom, Tonic+#
Sona		Wembley+, Solitaire
Axona		Axona+

* Temporary symbols
\+ cultivars on NIAB Recommended List
\# Resistance for Broom and Tonic similar but not the same

INTRODUCTION

The level of mildew infection remained low until about the middle of June since April was wet and May and early June were cool (ADAS Disease Intelligence Reports). The direct data of this survey confirms these observations. The

Table 2. Mean pathogenicity values relative to those on cv. Cerco for populations sampled in the roof nursery (1985-1986) and in the WIST (1986): a. differentials not replicated and cv. Cerco included 8 times; b. differentials and cv. Cerco replicated 4 times.

Sample source	Differential cultivars												No. of exposures
	Galahad	Longbow	Fenman	Norman	Avalon	Slejpner	Brock	Brimstone	Moulin	Mercia	Mission	Cerco*	
1985 roof	67	74	93	93	113	4	19	62	88	28	37	11.8	29
1986 roof	64	89	105	79	111	9	24	54	94	26	51	11.7	20
WIST a	60	99	109	104	151	11	28	81	139	28	37	4.1	9
WIST b	71	101	128	145	141	7	17	49	108	10	41	5.0	9

* colonies/seedling

Table 3. Comparison of variation between two methods in the WIST and one roof nursery using the coefficient of variation for each exposure

Method	No. of Cerco entries	Wilcoxon signed rank test	Mann-Whitney test	No. of exposures
WIST a	8	-13 ns (n=9)	T=71** $n_{1,2}$=9,20	9
WIST b	4			9
roof	7			20

maximum level of the epidemic was reached during the latter part of July when the warm, humid conditions were conducive to mildew development.

SURVEY OF PATHOGENICITY CHARACTERS

METHODS:

Direct: 1. Cultivars on the NIAB Recommended List were exposed in the wind impaction spore trap (WIST, Bennett and van Kints, 1981) on a 48 mile Cambridgeshire circuit. On each weekly journey 2 sets were exposed. (a) groups of 20 seedlings per cultivar, with groups of cv. Cerco seedlings between each pair of cultivars; unreplicated. (b) groups of 10 seedlings per cultivar, including cv. Cerco; replicated four times.

2. Sets of 20 seedlings of differential and commercial cultures were exposed on the roof of the Genetics Department, University of Cambridge. To observe the variation within the area occupied by the nursery seven sets of seedlings of cv. Cerco were distributed among the winter wheat entries and two among the spring wheat entries for every exposure. Length of exposures varied from 7 days at the beginning and the end of the epidemic, down to 2 days at the end of July.

Indirect: 1. Leaf samples from collaborators were maintained mostly as single colony isolates but some as bulk isolates. These were inoculated on to detached seedling leaf segments of cultivars on the NIAB Recommended List.

2. Single colony isolates were obtained from 12 cultivars in the roof nursery for which the major seedling resistance genes have not been characterized. These isolates were inoculated on to detached seedling leaf segments of cultivars from which they were sampled.

The methods used for direct and indirect tests were the same as described in previous survey reports (Bennett and van Kints, 1982; Summers and van Kints, 1985; Summers and van Kints, 1986). In the direct tests mean pathogenicity values were calculated by expressing the number of colonies on each cultivar as a percentage of those on the nearest placed cv. Cerco.

Pathogenicity for adult plant resistance characters was measured at the PBI by exposing seedlings of differential cultivars between plots of adult plants of those cultivars for six days at the time of scoring the adult plants for infection. Percentage infection was measured on leaf 1 of the seedlings and on the whole plot of the adult plants. Both scores were expressed relative to infection on cv. Cerco (Table 4).

RESULTS

Table 2 gives the relative frequencies observed by using direct methods. Comparing the results for the five cultivars with WMR2 on the 1986 NIAB Recommended list, values for cv. Galahad are consistently low and those for cv. Avalon consistently high, with the three closely related cultivar cvs. Longbow, Fenman and Norman in all but one case intermediate. This illustrates the danger of selecting one cultivar to represent a particular WMR group. It has been reported previously that seedling background resistance differs in cultivars with WMR2 (Bennett, 1981; Summers and van Kints, 1986), and all cultivars of current commercial importance were therefore included in the direct tests.

Mean pathogenicity values in 1986 were similar to those of 1985 (and 1984) as expected because the majority of the crop cultivars grown during those years had WMR2 alone or in combination with other resistance characters. Although

pathogenicity for cv. Slejpner (WMR7+?) is still the least common, it increased in 1986. This is expected to increase because it is known that pathogencity for WMR7 (Pm8) is rapidly selected in the presence of the host (Bennett and van Kints, 1982). In addition, cv. Hornet, which is provisionally recommended by NIAB, has WMR7. In the near future when the WMR2 cultivars are likely to be replaced by others with different or additional resistance characters more fluctuations in the pathogenicity frequencies are expected.

Since spring wheat is hardly grown, the differentials were exposed only in the roof nursery (not tabulated). Pathogenicity for cvs. Wembley, Solitaire, Tonic and Axona was observed in decreasing order respectively from relatively uncommon to not detected at all. Frequencies of pathogenicity for cvs. Jerico and Minaret remained around 40%, the same as in 1985.

Sampling the pathogen population by more than one method is particularly important because of the difficulty of applying statistical tests to the data. The different methods help to differentiate between changes that are consistent and are likely to be due to a shift in the population and those that occur through experimental error. However, an attempt was made to determine the most suitable method.

Table 3 compares the variation between the two WIST methods and the roof nursery. The variation between the counts on cv. Cerco was measured by calculating the coefficient of variation for each exposure for each method. In the WIST, method b had a lower coefficient of variation in 7 out of 9 exposures but this difference was not significant. When WIST b. was compared with the roof nursery, there was less variation for the roof exposures and this difference was significant (P=0.01). Apart from the low variation other advantages of monitoring on the roof are a higher colony count on the cv. Cerco control which can reduce the experimental error, and virtually no limit to the number of differentials that can be exposed at any one time.

It is clear from Table 4 that all the differentials express a considerable level of adult plant resistance, but some more so than others. Moreover, there was no correlation between seedling and adult plant infection. In particular, cv. Fenman had the most resistant adult plants, but the most susceptible seedlings. Cv. Mission on the other hand, had relatively susceptible adult plants, but relatively resistant seedlings. This contrast between cvs. Fenman and Mission was consistent for the three years, 1984-1986. Brock was the most resistant cultivar as seedling and adult plant, indicating that the intermediate resistance of the parent, Talent, is still effective.

Table 4. Mean percentage infection levels over 6 replicates relative to that on cv. Cerco for seedlings and adult plants of the same cultivars in the field in June.

Cultivar	Adult plant[1)]	Seedling[2)]
Fenman	6	125
Brock	9	22
Norman	14	104
Galahad	14	106
Longbow	20	113
Mission	21	56
Avalon	27	102
Brimstone	31	90

1) Percentage infection of cv. Cerco = 27
2) Percentage infection of cv. Cerco = 15

Table 5. Mean pathogenicity values relative to values on cv. Cerco of 141 single colony isolates collected on seedlings after exposure on the roof nursery.

Source cultivar	Test cultivar and WMR group													No. of isolates tested
	Tonic ?	Dauntless 7+?	Slejpner 7+?	Axona ?	Hornet 2+7	Mercia 8	Mission 4+8	Brock 2+Talent	Parade 2+6+8	Anfield 1	Broom 5+8+?	Wembley Sona	Solitaire Sona	
Tonic	14	0	0	12	0	32	94	43	71	41	32	32	33	10
Dauntless	0	40	18	0	29	46	57	57	40	27	0	30	21	11
Slejpner	0	13	25	0	32	28	32	46	53	2	3	0	1	20
Hornet	0	0	27	0	62	46	6	69	18	6	1	12	12	11
Mercia	8	10	2	0	7	52	38	37	55	27	9	18	14	11
Mission	3	11	4	0	5	31	97	40	42	33	16	17	20	12
Brock	2	7	8	0	8	33	42	31	48	19	7	14	17	13
Anfield	4	0	5	2	3	48	30	31	40	76	9	40	44	13
Broom	40	0	1	9	0	49	60	53	54	29	49	15	18	14
Wembley	1	0	0	0	6	46	71	57	61	83	8	54	39	5
Solitaire	3	17	5	3	21	46	83	53	52	68	2	54	40	10
Alexandria	0	8	10	1	16	48	51	45	47	30	7	28	27	11

Tables 5 and 6 show results from indirect tests of single colony roof isolates and leaf samples respectively. Combinations of pathogenicity characters were relatively common in the single colony isolates collected from the roof nurseries as shown by the values for cvs. Mission, Brock and Parade (Table 5).

Pathogenicity on test seedlings of cv. Brock was as low or lower in populations from cv. Brock than in those from other cultivars and all but one isolate was pathogenic on Brock. This confirms the data in Table 4 that the resistance inherited from cv. Talent is intermediate.

Pathogenicity for WMR7 cultivars was uncommon in the absence of the host resistance (see also Table 6). It is interesting therefore to observe in Table 6 that isolates from leaf samples of cv. Hornet were more pathogenic on WRM2 cultivars than isolates collected from these cultivars. Further tests are needed to determine whether this is a real effect. All of the 15 isolates pathogenic on cv. Dauntless (Table 5) were also pathogenic on cvs. Slejpner and Hornet. However, isolates from cvs. Hornet and Slejpner were not always pathogenic on cv. Dauntless. Therefore, cv. Dauntless must have resistance characters additional to WMR7.

Only 2 of the 10 isolates sampled from cv. Tonic but 7 of the 14 isolates sampled from cv. Broom were pathogenic on cv. Tonic; all the isolates which were pathogenic on cv. Tonic were so on cv. Broom. In addition, isolates from cv. Tonic had relatively high pathogenicity for cv. Broom. Cv. Tonic should therefore be considered to be in the same WMR group as Broom, even though they do not share all of their resistance characters.

There appears to be an association between resistance characters of cvs. Wembley and Solitaire and those of cv. Anfield, because the qualitative reaction was the same for all three cultivars to all but 4 isolates.

The pathogenicity values for single colonies of WMR2 cultivars (Table 6) inoculated to those same cultivars did not show specificity of seedling background resistance, since there were no detectable interactions between isolates and cultivars. As in the direct tests (Table 2) cv. Galahad was generally the most resistant and cv. Avalon the most susceptible against all isolates.

SURVEY OF FUNGICIDE INSENSITIVITY CHARACTERS

Seedlings grown from seed of cv. Cerco which had been dressed with four different concentrations of triadimenol were exposed in the WIST on the Cambridgeshire circuit (48 miles). After incubation the colonies were counted and expressed as a percentage relative to those on untreated cv. Cerco (Table 7).

The proportion of the pathogen population insensitive to 0.04 g a.i. of the chemical has remained stable during the last 3 years. But insensitivity to the other concentrations tested, including the field rate (0.375 g a.i.), increased again in 1986. No tests have as yet been carried out on insensitivity to the morpholines. This may well become necessary in future years if fungicides with this ingredient becomes more widely used.

Table 6. Mean pathogenicity values relative to values on cv. Cerco of 63 single colony and 3 bulk isolates obtained from adult plant leaf samples collected in the field.

Source cultivar	Test variety									
	Galahad	Longbow	Fenman	Norman	Avalon	Brimstone	Slejpner	Hornet	Brock	No. of isolates tested
Galahad	73	95	65	89	96	71	0	0	50	9
Longbow	66	78	76	78	91	73	8	8	41	11
Fenman	50	69	88	70	86	68	0	5	35	8
Norman	97	99	96	81	108	82	0	0	49	10
Avalon	75	97	77	96	106	71	0	7	53	13
Hornet	122	112	122	108	133	100	41	111	60	12
Bulks	90	92	93	102	105	94	0	0	56	3

Table 7. Colony numbers on cv. Cerco seedlings grown from triadimenol treated seed, relative to those on untreated cv. Cerco seedlings (values are means of direct scores obtained by exposure in the WIST, each week between May and August 1983-1986).

Year	Seed treatment (g a.i. kg^{-1})				No. of journeys
	0.04	0.125	0.25	0.375	
1983	51	18	-	-	11
1984	69	33	-	-	17
1985	66	32	14	5	15
1986	70	49	25	14	16

Table 8. Colony numbers on cv. Cerco leaf segments grown from triadimenol treated seed, relative to those on untreated cv. Cerco leaf segments, for single colony isolates, obtained from cv. Cerco seedlings grown from untreated and triadimenol treated seed, exposed in the WIST.

Seed treatment WIST seedlings (g a.i. kg^{-1})	Seed treatment leaf segments (g a.i. kg^{-1})				
	0.04	0.125	0.25	0.375	No. of isolates
Untreated	58	13	3	0	51
0.04	61	10	1	0	75
0.125	66	13	1	0	30
0.25	69	31	11	3	44
0.375	73	23	5	2	45

Table 8 shows indirect test data from single colonies growing on untreated and treated cv. Cerco seedlings after exposure in the WIST, inoculated on to detached seedling segments of untreated and treated cv. Cerco.

The values were consistently lower than those for 1985 (Summers and van Kints, unpublished) in contrast with direct data. However, the seed used for direct WIST exposure and indirect single colony tests were from the same source, making this difficult to explain. The difference between the two sets of data may have occurred as a result of factors operating in the time between WIST exposure and testing of the isolates. The indirect data do however confirm last years results showing that occurrence of single colony isolates with low to moderate levels of insensitivity was independent of treatment of trap seedlings. This is a change from observations prior to 1985 (Bennett and van Kints, 1984; Summers and van Kints, 1985), when insensitive phenotypes were lost from bulk samples after laboratory maintenance on untreated cv. Cerco. This could imply that they may have become fitter in the absence of fungicide.

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YELLOW RUST OF WHEAT

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Thirty two samples were received in 1986. The frequency of WYV 6 remained very high and that of WYV 4 and the WYV 1,4 combination increased substantially. For the first time, adult plant tests identified isolates which combined WYV 1,4 with the adult plant virulence WYV 13. A new isolate, 85/28, gave increased infection on adult plants of Avalon.

INTRODUCTION

The principal aim of the wheat yellow rust survey is to detect increased virulence for specific resistances to Puccinia striiformis, both of the overall and adult plant types. At the same time, specific resistances present in current and new cultivars are identified and the information used to construct a varietal diversification scheme. Specific resistances (WYR factors) identified in wheat cultivars to date, the resistance genes where known, differential cultivars possessing each resistance and the year of first detection of virulence (WYV) in the UK population of P.striiformis are given in Table 1.

Table 1 Resistance factors to Puccinia striiformis and differential cultivars

WYR Factor	Gene	Type*	Differential Cultivar(s)**	WYV detected
WYR 1	Yr 1	O	Chinese 166, Maris Templar	1957
WYR 2	Yr 2	O	Heine Vll, Brigand	1955
WYR 3	Yr 3a + 4a	O	Vilmorin 23, Cappelle Desprez	1932
WYR 4	Yr 3b + 4b	O	Hybrid 46, Avalon	1965
WYR 5	Yr 5	O	T. spelta album	
WYR 6	Yr 6	O	Heines Kolben, Maris Ranger	1958
WYR 7	Yr 7	O	Lee, Tommy	1971
WYR 8	Yr 8	O	Compair	1976
WYR 9	Yr 9	O	Riebesel 47/51, Clement	1974
WYR 10	Yr 10	O	Moro	
WYR 11	-	A	Joss Cambier	1971
WYR 12	-	A	Mega	1969
WYR 13	-	A	Maris Huntsman	1974
WYR 14	-	A	Hobbit	1972
Additional test cultivars 1986				
WYR 1,2,4			Brimstone	
WYR 1,2,4			Fenman	
WYR 1,9			Stetson	
WYR ?			Hornet	
WYR ?			Parade	

* O = Overall A = Adult Plant. Overall resistances are effective at all growth stages, adult plant resistances are ineffective at seedling growth stages.
** Differential cultivars used in 1986 seedling tests are underlined.

METHODS

Methods used at NIAB for seedling and adult plant virulence tests have been described by Priestley, Bayles and Thomas (1984).

1986 isolates

Thirty two samples were received, all from East and North East England and Scotland. Most had been collected from disease observation plots of a wide range of current and candidate varieties. Only five samples were from commercial crops.

Isolates were made from 23 samples. Seedling virulence tests, using the differential cultivars indicated in Table 1, were carried out.

1985 and control isolates

Table 2 Isolates of P striiformis used in adult plant tests

Code	Source Cultivar	Site	WYV Factors*
Control Isolates			
71/493	Capta	Duns, Scotland	1,2,3,7
72/852	Maris Ranger	Market Harborough, Leics	2,3,4,6,12
P75/27	Hobbit	PBI Cambridge	2,3,4,14
76/71	Grenade	Mains of Ravensby, Scotland	1,2,3,13
P79/4	TL 363/30/2	PBI Cambridge	1,2,3,14
P81/12	CWW 1684/15	PBI Cambridge	2,3,4,6
81/34	Vuka	Sparsholt, Hampshire	2,3,4,9
83/10	Stetson	Wye, Kent	1,2,3,9
83/62	Hammer	Oxford	1,2,3,6,13
84/1	Brimstone	NRPB Lincolnshire	1,2,3,4,6
84/11	Longbow	Wrangle, Lincolnshire	1,2,3,6,13
84/31	Brigand	Shoreswood, Northumberland	2,3,4,6,13,14
P84/F	Norman	PBI Cambridge	1,2,3,4,6
New Isolates			
85/2	Brigand	Winchburgh, West Lothian	1,2,3,4,6
85/3	Fenman	Friskney, Lincolnshire	1,2,3,4,6
85/8	Longbow	Alford, Lincolnshire	1,2,3,6
85/11	Longbow	Wigtoft, Lincolnshire	1,2,3,6
85/21	Longbow	Terrington, Norfolk	1,2,3,6
85/28	Avalon	Lt Eversden, Cambridgeshire	2,3,4,6
85/31	Gawain	Cockle Park, Northumberland	2,3,4,6
85/33	Un-named	NIAB, Cambridge	1,2,3,4,6

* Established from seedling virulence tests (all isolates) and previous years' adult plant tests (control isolates only).

Twenty one isolates were tested on adult plants of 36 cultivars in Polythene tunnels and on seedlings of the same cultivars in controlled environment chambers. The isolates comprised 13 control isolates of known virulence and eight new isolates (Table 2).

Polythene tunnel tests were sown on 23/24 October, inoculated on 19 March, 10 April and 25 April and assessed for percentage leaf area infected on 8 May (GS 40), 20 May (GS 50) and 4 June (GS 64).

RESULTS

1986 isolates

The survey is not a random population sample and changes in virulence frequency from year to year (Table 3) should therefore be interpreted with caution. The high frequency of WYV 6 was maintained in 1986 (96%), reflecting the continued popularity of WYR 6 cultivars. There was a marked increase in the frequnecy of WYV 4 and, correspondingly, in the frequency of isolates possessing the combined virulence WYV 1,4. This was not attributable to selective sampling from WYR 1,4 cultivars, since the isolates concerned were derived from a wide range of cultivars with contrasting genetic backgrounds. There was an apparent increase in the frequency of WYV 7, despite the fact that WYR 7 cultivars occupied less than 4% of the wheat acreage in 1986 and are unlikely therefore to have had a significant impact on the yellow rust population.

Table 3 Virulence factor frequency (%)

WYV Factor	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
WYV 1	92	73	73	83	95	71	63	85	75	76	78
WYV 2	100	100	97	100	100	100	100	100	100	100	100
WYV 3	100	100	100	100	85	95	100	100	100	100	100
WYV 4	12	24	27	17	15	29	37	20	31	45	70
WYV 5	0	0	0	0	0	0	0	0	0	*	*
WYV 6	4	16	26	17	25	31	29	26	64	90	96
WYV 7	0	8	0	0	0	5	5	0	3	3	22
WYV 8	2	4	0	0	0	0	2	0	0	*	*
WYV 9	6	0	0	0	0	5	2	23	31	3	4
WYV 10	0	0	0	0	0	0	0	0	0	*	*
Additional Cultivars 1986											
Brimstone	WYR 1,2,4								3	10	61
Fenman	WYR 1,2,4								3	14	61
Stetson	WYR 1,9								*	*	4
Hornet	WYR 9+?								*	*	0
Parade	WYR ?								*	*	0
No of isolates tested	52	26	26	30	20	42	41	63	36	29	23

1985 and control isolates

Adult plant infection data are summarised in Table 4. Seedling reactions are not tabulated as data are incomplete, but they are referred to in the discussion where appropriate. The identification of specific resistances is based on 1986 adult plant tests together with seedling and adult plant results from previous years and other isolates. Since all recent test isolates have possessed WYV 3, it has not been possible to detect the presence of WYR 3 in new cultivars and this WYR factor has therefore been omitted from the listed identifications. Boxes in the body of the table are used to highlight apparent cultivar x isolate interactions and have no statistical significance.

Four new cultivars (Rendezvous, Hornet, Dauntless and the hybrid H48) and eight new isolates were tested in 1986. Rendezvous and Hornet possessed adult plant resistance effective against all isolates, although they differed at the seedling stage, Rendezvous being susceptible to most isolates and Hornet resistant. Dauntless interacted with isolates possessing WYV 9 as a seedling, but was susceptible only to the WYV 1,9 isolate (83/10) in adult plant tests. H48, which was seedling susceptible to all isolates, was resistant to most isolates as an adult plant, but was moderately severely infected by one isolate, 84/31. There is no obvious explanation for this interaction.

Three 1985 isolates were virulent on Fenman and Brimstone and therefore possessed WYV 1,2,4 in combination with other virulences. Of these, two originated from cultivars without the corresponding resistance, confirming that there is no strong selection against the WYV 1,4 combination. The apparent virulence of another new isolate, 85/31, for Fenman and Brimstone, was probably due to contamination arising during adult plant tests. Three WYV 1,4 isolates (Box A) did not possess additional virulence for adult plant resistances. However, those in Box B gave high levels of infection on Maris Huntsman, Hustler and Longbow, indicating virulence for WYR 13. The addition of WYV 13 did not increase the virulence of isolates for Fenman or Brimstone. This is the first time that isolates combining WYV 1,4 with WYV 13 or WYV 14 have been detected in the course of the Survey and is evidence of a rapidly broadening virulence spectrum in response to the complex resistances of current cultivars.

Avalon interacted with isolates possessing WYV 4,14 (Box C), although high levels of infection were also recorded with certain other isolates possessing WYV 4 alone ie 84/1, 85/33, 72/852 and 83/10. The influence of WYR 14 on the resistance of Avalon is not clear cut. A new isolate, 85/28, from a naturally infected plot of Avalon, produced the highest level of infection yet recorded on this cultivar in Polythene tunnel tests. Further tests will be required to confirm that this isolate represents a real increase in virulence for Avalon.

Results for Longbow (WYR 1,2,6,13) again demonstrated two levels of adaptation to the cultivar, with WYV 1,2,6 isolates giving moderate infection and WYV 1,2,6,13 isolates increased infection. In the case of Norman (WYR 2,6), isolates which possessed WYV 1 in addition to WYV 2,6 appeared to give the greatest infection. This could be explained in terms of expression of WYR 1 in Norman at the adult plant stage. However, it is quite likely that, in the set of isolates used here, variation in WYV 1 was correlated with variation in some other, unidentified, virulence.

As in previous years, there was a tendency for certain cultivars designated WYR 9 at the seedling stage to be more severely infected by a WYV 9 isolate which also possessed WYV 1, 83/10 (Box E). There is some confirmation of earlier indications that 83/10 also possesses the adult plant virulence WYV 13 and it is possible that it is this, rather than WYV 1, which accounts for its increased virulence on some WYR 9 cultivars. Despite concern last year about the poor level of resistance shown by Slejpner, this cultivar clearly developed adult plant resistance at later growth stages, having been equal in susceptibility to Stetson at the initial GS 38 assessment. The implications of this pattern of disease development for field crops of Slejpner have yet to be seen, but it appears that early epidemics of yellow rust could be extremely damaging.

Table 4 Results of Adult Plant Tests 1986. Values are per cent leaf area infection (mean of 3 assessment dates).

Isolate and WYV Factors		84/1	85/33	P84/F	84/11	85/8	83/62	85/21	85/11	85/3	85/2	85/31	85/28	P75/27	84/31	P81/12	76/71	P79/4	71/493	72/852	81/34	83/10
Cultivar	WYR Factors**	1,2,3,4,6	1,2,3,4,6	1,2,3,4,6	1,2,3,6,13	1,2,3,6,13	1,2,3,6,13	1,2,3,6,13	1,2,3,6,13	1,2,3,4,6,13	1,2,3,4,6,13	1*,2,3,4,6, 13,14	3,4,6,14	2,3,4,14	2,3,4,6,13, 14	2,3,4,6,7*, 9*,13,14	1,2,3,13	1,2,3,14	1,2,3,7	2,3,4,6,12	2,3,4,9	1,2,3,4*,9, 13
Aquila	R?	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0
Rendezvous	?+APR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mission	R?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parade	R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hornet	R (9+?)	0	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	0	0	0	0	0
Maris Templar	1	17	11	8	6	14	16	18	10	18	10	9	5	0	4	3	22	23	15	1	5	16
Maris Beacon	4	26	19	25	1	9	7	9	14	26	9	28	10	30	22	10	3	0	3	5	26	13
Fenman	1,2,4	7	6	5	0	0	0	0	0	7	4	2	0	0	0	0	0	0	0	0	0	0
Brimstone	1,2,4	22	9	10	0	0	0	2	1	11	6	9	0	0	0	0	0	0	0	1	0	0
Avalon	4,?14	8	7	3	0	2	0	6	3	7	3	14	23	9	7	6	2	1	0	11	5	10
Rapier	2,4,14	4	2	0	0	1	0	3	4	1	0	11	1	11	10	4	2	2	1	3	5	5
Ranger	6	16	17	12	10	14	19	18	20	23	16	15	23	6	12	11	2	4	2	20	9	3
Kinsman	6,13	14	12	18	31	32	40	29	31	26	29	20	14	12	39	19	10	15	9	14	17	2
Moulin	6,14	1	0	8	0	5	3	6	12	2	3	18	19	5	3	5	4	0	0	1	2	0
Norman	2,6	18	11	16	15	18	21	20	13	27	18	13	3	6	5	3	3	5	2	1	4	0
Longbow	1,2,6,13	9	10	10	11	26	27	23	19	21	20	16	12	1	4	1	3	2	0	0	9	0
Tommy	7	1	1	0	0	0	1	0	1	15	1	0	1	0	0	20	0	1	35	1	0	1
Brock	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	5	0	1	0
Clement	9	3	1	0	0	0	2	0	0	4	0	0	2	0	1	19	1	1	1	3	26	29
Stuart	9	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	10	18
Slejpner	9	3	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	7	17
Ambassador	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Corinthian	9	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2	8
Dauntless	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Stetson	1,9	5	0	0	0	0	1	0	0	2	0	0	2	0	0	2	2	2	0	6	17	40
Armada	12	0	0	0	0	0	0	0	0	0	0	2	1	0	3	0	0	0	0	14	1	1
Huntsman	2,13	6	4	3	13	17	17	14	6	26	21	20	4	9	12	12	15	5	4	0	5	14
Hustler	1,13	2	3	4	11	16	25	19	18	26	24	24	4	0	1	5	18	3	1	2	10	18
Hobbit	14	3	7	3	2	4	3	8	6	4	5	16	22	16	11	9	3	16	5	5	8	5
Brigand	2,14,?13	3	5	6	12	10	14	7	5	13	12	24	2	10	5	14	8	13	1	0	8	6
Gawain	2,14,?13	8	4	1	10	10	12	11	8	14	10	18	5	11	13	4	9	4	0	0	8	7
Galahad	1,2,14	0	0	0	0	0	0	0	0	0	2	0	1	1	0	1	0	1	0	0	0	0
H48	0+APR	0	2	0	0	0	0	0	0	0	0	0	0	0	7	1	0	0	0	0	0	0
Mercia		6	3	2	2	4	6	3	1	7	2	1	10	3	0	2	3	1	2	6	2	1
Cappelle		15	8	8	8	13	18	10	4	11	13	14	21	12	11	13	14	5	13	17	11	15
Michigan Amber	0	20	38	27	25	28	28	26	34	41	26	41	37	26	33	20	29	14	15	27	19	23

*=contamination
** - omitting WYR 3 (see 3rd page of this report for explanation).
R=resistant to all isolates
R?=specific resistance factors unidentified

Considerably higher levels of infection were found on Mercia in 1986 than in 1985, when the maximum mean infection was 2%. There was no clear pattern of interaction with isolates and, although the highest levels of infection were produced by two new 1985 isolates (85/8 and 85/28), older isolates such as 84/1, 83/62 and 72/852 performed very similarly. It is probable that environmental effects conditioned the apparent increased virulence of these isolates for Mercia in 1986.

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BROWN RUST OF WHEAT

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The isolates of brown rust cultured from the 12 leaf samples of wheat received in 1986 were tested on seedlings of the differential cultivars under both a low and high temperature regime. The spring cultivar Jerico appears to have a temperature-sensitive resistance which is effective at the high temperature regime (25°C) but is ineffective to some isolates at the low temperature regime (10°C). Cultivars Wembley and Solitaire also appear to have a temperature-sensitive resistance which is more effective to some isolates at the lower temperature. Adult plant field tests identified several new winter and spring wheat cultivars with effective resistance to isolates WBRS-83-86 (Avalon virulent) and WBRS-74-2 (Huntsman virulent).

SEEDLING TESTS WITH 1986 ISOLATES

Twelve leaf samples of Puccinia recondita were received in 1986, six of these were from polythene tunnel tests at NIAB, Cambridge which had been inoculated with specific isolates. A further three isolates were received from National List trials at the same location. The remaining three samples were from cv. Avalon from Northumberland and Cambridge together with one sample from cv. Longbow sampled in Wales. Isolates were obtained from all the samples and were tested on differential cultivars which comprised the standard WBR reference cultivars, cv. Thatcher backcross lines carrying different resistance factors, and seven other lines from Australia (Table 1). The spring wheat cultivars Axona, Broom, Wembley, Tonic, Jerico, Alexandria and Minaret which are on the NIAB Recommended List together with Solitaire and Sapphire were also included. The tests were conducted under two different post-inoculation environments; a low temperature regime (10°C and 12 h photoperiod) and a high temperature regime (25°C and 16 h photoperiod).

Table 1. Differential cultivars

Standard differential cultivars		Thatcher Lr lines	Australian lines
Clement	(WBR-1)	Lr 1	Gatcher (Lr 27)
Maris Fundin	(WBR-2)	Lr 2a	Thew (Lr 20)
Norman	(WBR-2)	Lr 3	Transec (Lr 25)
Hobbit	(WBR-2)	Lr 3bg	CS70/Ag#11 (Lr 29)
Sappo	(WBR-3)	Lr 3ka	TS + Lr 30 (Lr 30)
Maris Halberd	(WBR-4)	Lr 9	CS20/2M[(Lr 28)C77.19](Lr28)
Gamin	(WBR-6)	Lr 15	ST-1 sel (CN 78.113) SR susc.
Sterna	(WBR-7)	Lr 19	
Sabre	(WBR-7)	Lr 24	
Armada	(WBR-0)		

Results

Isolate/cultivar interactions were assessed on the standard 0-4 scale and classified as resistant (R:0-2) or susceptible (S:3-4). These data are presented in Table 2. In cultivars with temperature-sensitive resistance factors (WBR-2,3,4 and 7), interactions were classified as susceptible only if that reaction was expressed at both temperatures.

Table 2. Classification of seedling reactions of differential cultivars to 1986 pathogen isolates

Cultivar	WBR factor	Isolate WBRS-86- 1	2	3	4	5	6	7	8	9	10	11	12
Clement	1	S	S	R	R	R	S	R	R	R	S	S	R
Fundin	2	S	S	S	S	S	S	R	S	S	R	S	S
Norman	2	S	S	S	S	S	S	R	S	S	R	S	S
Hobbit	2	R	S	I	S	S	S	R	S	S	R	I	I
Sappo	3	R	R	R	S	R	S	R	R	S	S	R	R
Halberd	4	R	R	R	S	R	S	R	R	S	S	R	R
Gamin	6	S	S	S	S	S	S	S	S	S	S	S	S
Sterna	7	R	R	R	R	R	R	R	R	R	R	R	R
Sabre	7	R	R	R	R	R	R	R	R	R	R	R	R
Armada	0	S	S	S	S	S	S	S	S	S	S	S	S

Virulence to WBR-1 in cv. Clement, which is derived from a rye translocation, was detected in five of the isolates at both temperature regimes.

The temperature-sensitive resistance WBR-2, present in cvs Maris Fundin, Norman and Hobbit was effective against only two of the isolates at both temperatures. One of these isolates (WBRS-86-7) was also avirulent on cv. Clement (WBR-1).

Three isolates gave a fully compatible reaction at both 10° and 25°C on the cvs Sappo (WBR-3) and Maris Halberd (WBR-4): the remaining isolates gave a mixed response on these two cultivars, but were more virulent at the higher temperature, thus confirming the temperature-sensitivity of these resistances.

All the 1986 isolates were virulent on cvs Gamin (WBR-6).

Cultivars Sabre (WBR-7) and Sterna (WBR-7) were resistant to all 12 isolates at 25°C but virulence was expressed in nine of the isolates at 10°C, although this was of a mixed susceptible type.

The spring cv. Jerico gave a resistant or mixed resistant reaction to the isolates at 25°C but was susceptible to five of the isolates at 10°C. Cultivars Wembley and Solitaire were less susceptible to some of the isolates at the low temperature and the latter was resistant (mixed reaction type) to isolate WBRS-86-7 at this temperature.

The detected virulences occurred in various combinations.

WBR virulence formula	No. of isolates
1,2,6	3
1,2,3,4,6	1
1,3,4,6	1
2,3,4,6	2
2,6	4
6	1

The nine Thatcher backcross lines, which carry known specific Lr genes, were selected for further study because of their largely resistant reactions in previous years' tests. Resistance conferred by Lr 1, Lr 3bg, Lr 9, Lr 19 and Lr 24 was effective at both 10° and 25°C against all isolates tested. Resistance conferred by Lr 2a and Lr 3 was temperature-sensitive but was effective against all isolates at the higher temperature whilst the converse was true of Lr 15. Six isolates were virulent on Lr 3ka.

Responses of the Australian Lr lines were difficult to interpret because of the mixed reactions recorded. A range of responses from 0c to 3 occurred commonly which may have been due to gene expressivity or to heterogeneity for virulence in the pathogen. Further tests using mono-uredial or mono-spore isolates would be necessary to further elucidate the situation. No fully compatible reactions were observed on Transec (Lr 25), CS70/Ag#11 (Lr 29), CS20/2M (Lr 28) or ST-1 sel. Full compatibility (virulence) to Thew (Lr 20), Gatcher (Lr 27) and Tc + Lr 30 (Lr 30) was detected in several isolates.

ADULT PLANT TESTS IN FIELD ISOLATION NURSERIES

Two isolates were tested on adult plants in field isolation nurseries in 1986. The isolates used were:

Isolate	Origin and description
WBRS-74-2	Cv. Maris Huntsman, Morley: Huntsman virulent
WBRS-83-86	Cv. Rapier, Somerset: Avalon virulent

Each nursery comprised 33 winter and eleven spring wheat cultivars, replicated three times. Assessments of percentage infection and reaction type were made throughout the season.

Results

These are summarised in Table 2. Infection levels within the nursery inoculated with isolate WBRS-74-2 were lower than those in the other nursery, particularly amongst the spring cultivars where brown rust was slow to develop. Results confirmed the previous grouping of cultivars according to their resistance factors. Differences in levels of infection and infection type were noted on the WBR-2 cvs Maris Fundin and Hobbit. This confirms previous observations (Clifford et al., 1982) that Hobbit carries an additional resistance factor(s).

Although Brigand was susceptible, these tests were conducted on the original seed stock. A re-selection has been made which is more resistant and this will be tested in future years.

Isolate WBRS-83-86 was virulent on cv. Avalon, but was not able to overcome the temperature-sensitive resistance of cvs Virtue, Hustler and Rapier which remains effective against all isolates tested in the field to date.

The resistance of the winter wheat cultivars Moulin, Ambassador, Rendezvous, Dauntless, Slejpner, Brimstone, Corinthian and Gawain was effective against both isolates, as was that of the spring cultivars Sapphire, Jerico, Axona and Broom.

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Table 3. Results of adult plant tests with specific isolates of *Puccinia recondita* in field isolation nurseries

Cultivar	WBR factor	Isolate WBRS-83-86	WBRS-74-2
Clement	1	+0.1 MS	0
Norman	2	6.5 MS	2.5
Fundin		12	1 MS
Hobbit		4 MS	3 MS
Sappo*	3	12	2
Halberd*	4	7	1
Huntsman	5	15	8
Brigand		18 MS	5 MS
Gamin	6	20	12
Sabre	7	0	0
Sterna		0	0
Maris Ranger	8	3 MS	0.5 MS
Kinsman		0.75	0
Avalon	9	10	0.5 MS
Rapier		Tr R	0
Virtue		0	0
Hustler		0	0
Moulin		0	0
Ambassador		0	0
Rendezvous		0	0
Dauntless		0	0
Slejpner		0	0
Sapphire*		0	0
Jerico*		0.1 MR	0
Axona		0	0
Brimstone		2 MR	0
Broom*		2 MR	0
Corinthian		0.2	0
Gawain		5 MR	0
Aquila		0.2 MS	0
Hornet 1		2 MS	0
Mercia		4 MS	5
Galahad		8	4
Wembley*		8	1
Minaret*		9	1 MS
Longbow		10 MS	5 MS
Parade		8	1
Solitaire*		10	1
Tonic*		10	1
Alexandria*		11	1
Fenman		10	5
Brock		12	5
Mission		12	6
Armada		14	6

All reaction types susceptible unless stated
R = resistant; MS = Mixed susceptible; MR = Mixed resistant
+ = % infection for mean of 3 replicates at 4 assessment dates (winter cultivars) and 2 assessment dates (spring* cultivars)

MILDEW OF BARLEY

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Isolates pathogenic on cultivars derived from cv. Rupee were identified from the field for the first time, which facilitated characterisation of the resistances of several new cultivars. A low degree of pathogenicity was confirmed among isolates obtained from cv. Atem at a site in northern England.

Other new cultivars carry combinations of previously used resistance genes which select for pathogen phenotypes that have previously occurred at lower than expected frequencies in the pathogen population. This unfortunate trend is likely to be deleterious to the potential for cultivar diversification.

Isolates have been identified from Scotland with a low but stable level of insensitivity to fenpropimorph. As with cultivar resistance, it is evident that the pathogen is now responding to selection by mixtures of fungicides that have been previously used singly, which may prove deleterious to fungicide diversification.

Identification of resistance phenotypes

Isolates pathogenic on cultivars with cv. Rupee resistance (Mla13, Ru2, Ru3) were obtained from the field for the first time. From tests with these and other isolates, cvs. Sherpa and Pipkin probably have Ru2 combined with Mla12, but the greater quantitative resistance of cv. Sherpa may be due to another factor, possibly from the parent, cv. Maris Mink. Cvs. Clansman, Digger and Sergeant probably all have Mla13 combined with Ru3; they may also possess Ru2. At least one of the new isolates is pathogenic on all five cultivars, but to a lesser extent on cv. Sherpa.

Isolates were obtained from infected fields of cv. Atem (MlLa, mlo) in Northumberland. In a blind test assessed by Dr E Schwarzbach, the isolates were shown to have a low but significant level of quantitative pathogenicity specific for cv. Atem. The level was similar to that found in the same season in Austria and Poland.

Pathogen population structure

Table 1 lists the principal differential cultivars used in the survey.

Table 1. Principal differential cultivars for pathogen isolates.

BMR gp	Cultivar	BMR gp	Cultivar	BMR gp	Cultivar
0	Gold. Promise	6a (Mlk)	H. 1063	10a(Mla13)	Digger
1a	W. 37/136	6b (Mla7)	Porter	4,6b	Doublet
1b	W. 41/145	6ab	Ark Royal	4,6ab	Klaxon
2 (Mlg)	Julia	6bc(Mla7,Ab)	Triumph	4,7	Vista
3 (Mla6)	Midas	7 (Mla1)	Delta	4,8	Kym
4 (MlLa)	Lofa	8 (Mla9)	Simon	5,6c	Natasha
5 (Mla12)	Hassan	9 (mlo)	Apex	5,10b(MlRu2)	Sherpa

Changes in frequency of the major pathogenicity characters in recent years are shown in Table 2. This Table is based solely on data from isolates taken from winter barley cultivars, to indicate the frequencies of pathogenicity genes coming from the largely non-selective winter host population which provides the main source of inoculum for the spring crop. Previously, the data included pathogen populations from both the winter and spring crops which confounded the effects of differential selection.

Table 2. Changes in frequency of the major pathogenicity characters since 1978 determined from samples from winter barley cultivars

	BMV character									
Year	1b	2	3	4	5	6a	6b	6ab	6bc	7	8
1978	-	68	34	7	28	51	-	35	0	0	0
1979	-	39	20	13	16	44	-	34	0	0	0
1980	-	61	27	16	21	-	-	38	2	5	0
1981	-	44	31	45	23	-	-	7	4	1	0
1982	-	48	45	31	41	-	-	18	4	1	0
1983*	-	68	43	36	42	-	-	29	37	3	0
1984	56	47	51	15	13	-	-	52	52	1	1
1985	45	45	43	18	21	49	42	-	47	-	2
1986	26	28	23	8	24	26	23	-	24	1	2

* NIAB trials samples in 1983

From Table 2, the majority of pathogenicity characters decreased in frequency from 1985 to 1986, partly due to the decrease in popularity of cv. Triumph, and partly due to the increased cultivation of currently resistant cultivars. The decrease for BMV 2 appeared to relate only to the unidentified resistance gene in cv. Julia; pathogenicity for Mlg (cv. Goldfoil) has remained high since the 1960's. The slight increase in BMV 5 was probably due to infection of cv. Natasha (BMR 5, 6c).

WIST data obtained from a wider area revealed more general increases in the frequencies of pathogenicity characters (Table 3). The reason for the apparent increase in BMV 3 in Scotland is not known; cultivars with matching resistance tended to decrease during this period. The increases in the frequencies of BMV 4, 5, 6bc and 4,9 presumably reflect the increase in diversity of resistant cultivars in Scotland as the popularity of cv. Golden Promise continued to decline.

The effect of the trend towards increased areas of cultivars with complex combinations of resistance genes is shown in detail in Table 4 and diagrammatically in Fig. 1. Up to the last year or so, the pathogen population had been divided into two major sub-populations, characterised by the reactions on cvs. Patty and Triumph (Table 4). The Patty group tended to have high frequencies of BMV 4, 5 and occasionally 7 with unusually low frequencies of BMV 6, whereas the Triumph group had high frequencies of BMV 6 and unusually low frequencies of BMV 4 and 5.

The recent flush of new resistant cultivars is characterised by combinations of resistance genes that now cause selection in the pathogen population across the previous boundary. For example, cvs. Cameo (BMR 4,6a,8) and Kym (BMR 4,8) select for BMV 4 which, because of linkage disequilibrium, also carries along a relatively high frequency of BMV 5.

Table 3. Distribution of major pathogenicity characters from 1984-86 determined from direct tests in the WIST (roof data for Cambr.)

Year	Region					
	Cambr.	E. Mids	N. Eng	Lothns	E. Sctl	N. Sctl
BMV 3						
1984	-	62	73	48	36	23
1985	27	27	36	53	55	46
1986	19	31	55	56	125	86
BMV 4						
1984	-	37	56	27	35	51
1985	22	19	28	47	55	15
1986	29	22	50	47	77	44
BMV 5						
1984	-	18	51	27	39	40
1985	26	27	23	54	74	21
1986	31	46	58	68	148	32
BMV 6bc						
1984	-	91	21	21	15	16
1985	20	39	17	33	62	23
1986	28	44	66	81	54	61
BMV 4,9						
1984	-	4	4	9	0	5
1985	4	12	10	20	2	2
1986	2	5	22	8	10	13

Simultaneously, the linkage disequilibrium associated with selection for BMV 6a and 8 results in a high frequency of BMV 6b in the populations on these cultivars. However, the high frequency of BMV 6a and 6b has not led to a high frequency of the common pathogenicity BMV 6b,c (cv. Triumph).

Cvs. Auto (BMR 3,4,6a), Doublet (BMR 4,6b) and Klaxon (BMR 4,6a,6b) select for the same fraction of the population since BMV 8 occurs at a high frequency, BMV 6bc is uncommon, and the effects of linkage disequilibrium are similar. Cv. Everest is similar, but probably carries BMR 6c in addition to BMR 4,6b, so that pathogenicity for cv. Triumph is more common and for BMR 8 less so, than on the other three cultivars.

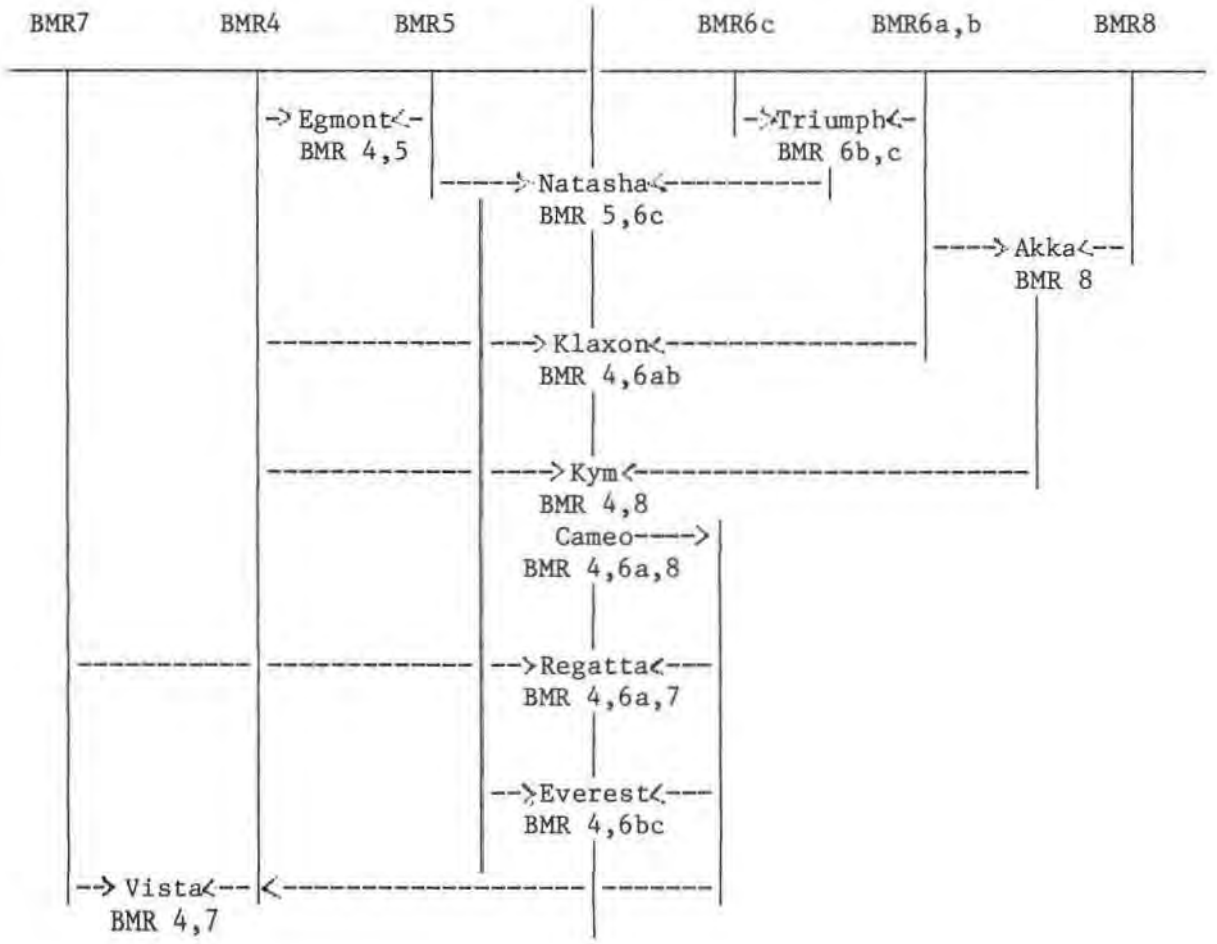
Increased infection of these cultivars may encourage survival of Atem-pathogenic isolates because of the high frequency of BMV 4. Previously, isolates pathogenic on cv. Atem would have failed on the large area of cv. Triumph because of selection against BMV 4 on the latter cultivar.

Cvs. Blenheim, Corniche, Kingpin and Natasha all have BMR 5,6c. In this case however, the linkage disequilibrium between BMV 4 and 5 has been reversed, and BMV 4 occurs only at low frequencies. The diseqilibrium between BMV 6a and 6b has also been affected in that the frequency of the unselected BMV 6a was considerably lower than in the other populations. In the pathogen populations on this group of cultivars, therefore, there appears to have been selection against unnecessary pathogenicity genes.

Table 4. Frequencies of pathogenicity characters in leaf samples from new cultivars with combined resistances.

	BMV character													
Cv.	3	4	5	6a	6b	6bc	7	8	4,6b	4,6ab	4,6bc	4,7	4,8	5,6c
Patty	6	38	73	9	1	0	0	11	0	0	0	0	8	2
Triumph	21	2	8	52	41	50	0	0	0	0	0	0	0	10
Auto	39	25	25	89	43	8	0	48	8	48	19	0	43	4
Doublet	3	26	62	70	67	0	0	29	42	78	31	0	24	11
Klaxon	12	40	20	69	57	6	0	24	24	51	27	0	24	5
Everest	19	29	34	60	78	26	0	10	35	57	50	0	13	6
Cameo	27	38	30	90	51	1	0	69	15	54	28	0	79	2
Kym	32	34	24	59	30	3	3	52	8	40	16	1	66	2
Vista	10	33	49	19	11	0	130	5	3	2	14	137	29	2
Regatta	16	32	12	63	27	0	106	11	3	18	31	106	18	1
Blenh'm	7	8	57	15	56	39	0	0	0	0	2	0	0	55
Cornich	4	3	70	15	42	31	3	0	0	0	0	0	1	57
Kingpin	11	3	52	33	50	41	0	0	0	3	1	0	3	64
Natasha	12	3	50	12	40	35	0	0	2	1	1	0	0	62

Fig. 1. Diagrammatic representation of recent trends in barley breeding affecting pathogen evolution.



Introduction of cultivars with combined resistances is unfortunate, first, because their effectiveness is likely to be ephemeral. Second, the potential for diversification either between or within fields is reduced. Third, the long-standing separation of BMV 4 and 5 from BMV 6a, 6b and 8, could be lost. Fourth, the probable increase in the BMV 4 population may endanger the resistance of cv. Atem (BMR 4,9). Fifth, if there is a large increase in the absolute frequency of recombinant phenotypes of the pathogen, then cultivars with combined resistances and those with separate components may all become highly infected (Wolfe & Barrett, 1976).

Pathogen response to fungicides

Compared with 1985, there was an increase in higher levels of insensitivity to triazoles in East Anglia although performance of the pathogen against low doses of the fungicide decreased (Table 5). These changes probably reflect a swing in the pathogen population towards a higher frequency of the highly insensitive genotype, which has a relatively flat dose response curve, and a lower frequency of the less insensitive genotypes which have steeper response curves.

Table 5. Change in triazole insensitivity over years in barley mildew in East Anglia: direct WIST counts of colonies relative to untreated control.

	Year					
Dose	81	82	83	84	85	86
0.025 (1/15)	23	51	83	85	64	52
0.075 (1/5)	-	27	54	54	70	62
0.125 (1/3)	-	-	-	24	43	45
0.250 (2/3)	-	-	-	-	-	74
0.375 (1/1)	-	-	-	-	-	44

The shift between these classes of insensitivity towards higher levels was also evident within the 1986 season from samples taken at different times.

The increase in triazole insensitivity was widespread (Table 6). This general change in 1986 was probably brought about by the rapid increase in the use of Ferrax. This is partly confirmed by the general increase in ethirimol insensitivity (Table 6). Data from indirect tests of isolates from the Genetics Department roof also indicated a considerable increase in the response to Ferrax, particularly late in the season. In comparing the response of the pathogen to 1/5 field rate of Ferrax and Milstem, there tended to be many more colonies on the Ferrax-treated leaves which presumably is due to the half rate of ethirimol in the mixture relative to that in commercial Milstem. It suggests that although the pathogen is responding to Ferrax, it is still being controlled by high rates of ethirimol, but this may not be maintained under selection.

The potential problem with Ferrax was highlighted by evidence reported last year from local analyses of populations, that insensitivity to both triazoles and ethirimol was positively and significantly associated.

Table 6. Regional changes with time of pathogen insensitivity to triadimenol and to ethirimol (WIST data from triadimenol and ethirimol treated seedlings).

Source	Triadimenol 1:3			Ethirimol 1:5		
	1984	1985	1986	1982	1985	1986
E. Anglia	24	43	45	-	16	15
E. Midls	80	60	62	2	17	25
N. Engl	35	27	48	2	3	11
Lothians	22	17	55	4	25	27
E. Scotl	16	28	44	5	12	31
N. Scotl	12	11	85	6	15	16
mean	32	31	57	4	15	21

Table 7 summarises the results of indirect tests for fungicide response among isolates obtained from seedlings treated in different ways and exposed in different regions. Colony numbers on the triadimenol-treated leaf segments were highest for the populations collected on triadimenol-treated plants, but were low, relatively, only for the populations collected on fenpropimorph-treated plants.

In a similar way, colony counts on the ethirimol-treated segments were highest for the populations from ethirimol-treated plants. From other sources they tended to be noticeably lower except, perhaps, from the triadimenol-treated plants. As expected, the colony counts on Ferrax-treated leaf segments were also highest for the populations from the ethirimol-treated plants since ethirimol provides the only effective bottleneck for isolates with combined insensitivity to triazoles and ethirimol.

A response to tridemorph was evident in samples from England, but not from Scotland, but the size of the response was perhaps too small to be screened out on the tridemorph-treated trap seedlings. Isolates trapped on the fenpropimorph-treated seedlings grew to some extent on all of the morpholine-treated test material. One of the bulk isolates involved was re-tested on three occasions and gave a consistent positive response to fenpropimorph. These results suggest that there may be one phenotype, relatively common in England, that has a low level of insensitivity to tridemorph but which is sensitive to fenpropimorph. A different phenotype occurs less commonly in Scotland that gives a low level of cross-insensitivity to tridemorph, fenpropimorph and fenpropidin.

As expected, leaf segments treated with Tilt Turbo or Dorin, both of which are triazole-tridemorph mixtures, gave high colony counts with populations that had high counts for the fungicide components separately. Indeed, the data from Scotland indicate that there may already exist genotypes that recombine moderate insensitivity to triazoles and ethirimol with low insensitivity to tridemorph and other morpholines. In this sense, the use of mixtures of fungicides containing components that have been previously exposed separately, is analogous to recombination of previously exposed resistance genes in host cultivars. In either case, the initially large extra effect in controlling mildew is likely to be short-lived (Wolfe & Barrett, 1976).

Table 7. Indirect tests of isolates obtained from different regions on seedlings untreated or treated with different fungicides. All tests completed in autumn 1986.

	Fungicide and rate relative to commercial application							
Source	Triad. 1:1	Ethir. 1:4	Frrx. 1:15	Trdph. 1:20	Fnprp. 1:100	Ptrl. 1:20	TltT 1:15	Drn. 1:20
Controls								
CC 1	0	25	0	7	4	0	0	0
83/209	0	1	0	17	2	1	21	27
83/3	69	28	20	3	0	0	19	25
85/379	63	0	0	13	0	0	21	37
Untrtd.								
Essex	87	34	12	44	0	0	24	77
E. Mids	35	21	12	23	1	0	34	33
N. Engl	60	30	12	22	0	0	24	34
Loths.	52	2	1	0	0	0	2	0
E. Sctl								
N. Sctl	48	3	4	0	0	0	1	1
Triad. 1:1								
Essex	122	8	20	38	0	0	39	49
E. Mids	54	43	16	19	2	1	28	42
N. Engl	87	89	26	19	0	0	27	49
Loths.	74	1	1	0	0	0	7	26
E. Sctl	45	24	13	0	0	0	4	2
N. Sctl	84	3	14	2	0	0	3	8
Ethir. 1:5,1:15								
Essex	46	11	11	3	1	0	26	25
E. Mids	164	75	14	11	0	0	73	96
N. Engl	44	58	45	23	0	0	22	34
Loths.	31	11	64	0	0	0	0	0
E. Sctl	81	25	12	0	0	0	0	0
N. Sctl	42	12	15	4	12	5	26	6
Tridem. 1:20								
Essex	57	24	8	10	0	0	24	29
E. Mids	58	1	2	0	0	0	0	14
N. Engl	53	0	0	0	0	0	0	0
Loths.	79	3	3	0	0	0	6	1
E. Sctl	68	3	1	0	0	0	2	1
N. Sctl	41	7	12	2	0	0	0	0
Fenprp. 1:100								
Essex	26	13	0	0	0	0	35	42
E. Mids								
N. Engl								
Loths.	28	13	22	20	19	34	37	19
E. Sctl	27	0	0	89	47	38	76	52
N. Sctl	2	44	26	18	41	80	73	12

European Survey

A recent meeting at Weihenstephan, FRG, supported by the CEC and EPPO, brought together research workers with a particular interest in monitoring the barley and wheat mildew pathogens in Europe. A review of all of the data presented, particularly including Dr E Limpert's survey over the whole area using the Schwarzbach jet spore sampler, provided an outstanding platform for further investigations, integration of the data, and the development of recommendations for the rational deployment of cultivars and fungicides.

The review will be published in 1987 and will cover barley and wheat mildew, with currently available information on frequencies of pathogenicity genes and fungicide insensitivity characters. It is hoped that this will provide a starting point for a regular survey, the results from which will be distributed as widely and as rapidly as possible. Because of the probable movement of large pathogen populations over the whole region, this initiative should be of great practical value to all of those concerned with disease control.

Molecular biology

Survey investigations at PBI are now being supported by work on restriction fragment length variation in the DNA of the barley and wheat mildew pathogen. Variation in DNA fragments extracted from infected leaf segments has been assessed largely from HindIII restriction digests by hybridisation with an intermediate repetitive DNA sequence, isolated and purified by cloning. Among an initial small group of randomly chosen isolates, variation proved to be extensive. Further tests were made, therefore, with a group of isolates again from different years and locations, but all of which carry the relatively uncommon character of pathogenicity for Mla9. Again, most isolates differed considerably, although two were indistinguishable except on a single band.

To focus more closely on variation within populations, 55 isolates were tested from the pathogen population established on cv. Atem (see above). DNA from these isolates was also digested with HindIII and hybridised with the same probe. Considerable variation was revealed suggesting a diverse origin for this population. On the other hand, the isolates pathogenic on Mla13, Ru2 and Ru3 were identical to each other. However, they differed considerably from pathogenically similar continental isolates, suggesting a different origin for them. Clearly, the sensitivity of the technique for comparisons among isolates underlines its potential for improving our understanding of the migration of populations. The banding patterns of all of the isolates tested so far are now being characterised precisely to facilitate the use of the data in a computer program to analyse relationships among the isolates by similarities and differences.

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MILDEW OF BARLEY IN NORTHERN IRELAND

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A combination of unsuitable conditions and the use of highly resistant cultivars meant that it was almost impossible to obtain any mildew isolates directly from plots in 1986. In order to get at least some isolates, trap plants of Golden Promise were placed in fields of known cultivars for 24 h, brought back to the laboratory and incubated in an isolation plant propagator. Any mildews which appeared were then transferred to differential cultivars. This method has the disadvantage that it is merely sampling the air spora in the vicinity of a cultivar rather than spores obtained directly from the leaves of the cultivar. Thus a mildew isolate was obtained from a field of cv. Atem even though there was no evidence of mildew pustules on the leaves. Even with this system only eight isolates were obtained. Table 1 shows the cultivars used for examining the various virulences.

TABLE 1 Test cultivars for the detection of virulence groups

BMR Group	Cultivar
0	Golden Promise
2	Zephyr
3	Midas
4	Varunda
5	Medallion
6ab	Keg
6bc	Triumph
7	Delta
8	Leith
3+4	Goldspear
4+5	Egmont
4+6a	Dram

Table 2 shows values for the mean pathogenicity of the isolates. Table 3 shows a comparison of non-corresponding pathogenicity values in N. Ireland for the last four years with those obtained in England and Scotland over the same period (Wolfe *et al* 1984; 1985; 1986; 1987).

The data appeared rather uneven and it was not clear if any of the pathogenicity values in Table 2 could be described as corresponding. However, in the calculations for Table 3 all possible corresponding figures were removed.

TABLE 2 Mean pathogenicity of bulk isolates in 1986 on test range of cultivars

			BMV characters										
BMR Group	Isolate Source	No.	2	3	4	5	6a+b	7	8	3+4	4+5	4+6a	6b+c
1	Igri	1	143	113	272	80	77	9	66	5	107	28	12
6b+c	Triumph	2	122	32	92	86	75	1	7	28	13	104	74
7	Delta	1	117	73	117	41	12	27	10	36	65	23	21
3+4	Goldmarker	2	173	60	158	74	21	1	5	49	37	8	14
4+mlo	Atem	1	170	113	172	123	87	2	59	100	105	77	119
4+6a+b	Klaxon	1	97	46	145	110	11	59	27	11	107	5	16

TABLE 3 Comparison of non-corresponding pathogenicity values in Northern Ireland and England, 1983-85

		BMV characters							
Location	Year	2	3	4	5	6ab	6bc	3+4	4+5
N. Ireland	1983	59	53	59	37	16	22	45	32
N. Ireland	1984	48	45	42	40	17	24	29	38
N. Ireland	1985	65	54	60	69	31	37	35	34
N. Ireland	1986	140	68	143	84	53	59	35	61
England	1983	63	49	35	30	17	22	11	14
England	1984	64	42	22	17	24	22	6	6
England	1985	39	40	15	14	30	32	14	11
England*	1986	-	35	34	45	-	46	-	-
Scotland	1983	49	57	27	33	14	13	8	3
Scotland	1984	69	54	24	27	39	19	26	7
Scotland	1985	-	41	39	30	17	14	-	-
Scotland*	1986	-	89	56	83	-	65	-	-

* Averaged data from WIST taken from Table 3 in "Mildew of Barley" (this report)

The main feature of the data on non-corresponding pathogenicity is the increase in value of most combinations in N. Ireland over the previous year with the exception of 3+4. 6b+c might have been expected to have increased because of the general breakdown in cv. Triumph resistance. However, most of the other groups were also higher than in the previous year. Groups 2 and 4 were well over the theoretical 100%. It was thought this was purely variation within the small number of samples but the test was repeated and with fresh Golden Promise seed produced very similar results the second time. Results from Scotland, however, were also considerably higher than in previous years, and some of the figures from which the averages were taken were also over 100%.

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MILDEW OF BARLEY : A NOTE ON COMBINING RESISTANCE GENES IN NEW VARIETIES

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Wolfe et al. (1987) comment in this year's UKCPVS report that, where single resistance genes have already been matched by a large fraction of the pathogen population, the effectiveness of cultivars with a combination of those resistance genes is likely to be ephemeral. Such cultivars may initially be highly resistant because the matching combination of virulence genes is uncommon. Recombinant genotypes which match the combined resistance, and mutants with the combined virulence that arise from a fraction of the population which has all but one of the required matching virulence genes may be selected by the new variety. Clones of the pathogen formed by both mechanisms may rapidly become very common.

Analyses of single colony isolates collected in 1985 and 1986 show how rapid this breakdown of new varieties with combined resistances can be.

Varieties and collections of isolates

I present here a summary of the data from three collections of single colonies of powdery mildew isolates. Each of these collections was taken from seedlings of cv. Golden Promise exposed on the roof of the University Genetics Department, in the centre of Cambridge. The collections can therefore be regarded as a random sample of the air spora of the powdery mildew pathogen at that time. The collections were made at the following times: JU85 in early July, 1985; JU86 in late June, 1986; and OC86 in mid-October, 1986. JU85 contained 99 isolates, JU86 contained 244 and OC86 contained 185.

The single colony isolates were tested on the differential set listed in Table 1.

Table 1 Differential set of varieties

Variety	Resistance genes	BMR
Golden Promise	Ml-a8 ?	0
Midas	Ml-a6	3
Lofa Abed	M-v	4
Hassan	Ml-a12	5
Hor. 1063	Ml-k	6a
Porter	Ml-a7	6b
Rhapsody	Ml-a6 + Ml-(Ab)	3+6c
Natasha	Ml-a12 + Ml-(Ab)	5+6c
Triumph	Ml-a7 + Ml-(Ab)	6b+6c

This enabled isolates to be classified for their virulence or avirulence alleles at the matching loci V-a6, V-v, V-a12, V-k, V-a7 and V-(Ab) (BMV 3, 4, 5, 6a, 6b and 6c respectively).

Results and discussion

The percentages of the isolates in each collection which were virulent on the six resistance genes tested are listed in Table 2.

Table 2 Percentage of isolates in each collection with virulence to the resistance genes tested

Resistance gene	BMV	Collection JL 85	JU 86	OC 86
M1-a6	3	61.6	34.4	19.5
M-v	4	16.2	15.6	49.2
M1-a12	5	27.3	42.6	71.4
M1-k	6a	67.7	43.0	62.2
M1-a7	6b	70.0	58.2	68.6
M1-(Ab)	6c	80.8	65.6	32.4

In Table 3, D', a measure of disequilibrium, the non-random association of alleles of two genes in the population, is given for each pair of virulence genes other than V-a6. V-a6 is not included here as no currently widely grown variety has the matching resistance gene M1-a6. $D' = \frac{D}{D_{max}}$. D is the usual measure of disequilibrium between alleles of two genes. As the range of possible values of D depends on the frequency of alleles in the population, D has been scaled by D_{max}, the maximum possible value of D given the allele frequencies observed, to give D'. The range of possible values of D' is therefore -1.0 to 1.0, whatever the allele frequencies observed (Hedrick, 1985). Changes in D' can indicate therefore, to what extent two alleles in two different genes have become more or less associated in the population, regardless of the changes in frequency of each allele independently. I have indicated to what extent D' is significantly different from 0.0.

Table 3 Allele frequency-independent disequilibrium (D') for pairs of virulence genes

Pair of virulence genes		BMV		Collection JL 85	JU 86	OC 86
V-v	V-a12	4	5	0.484***	0.596***	0.540***
V-v	V-k	4	6a	-0.538***	-0.572***	0.448***
V-v	V-a7	4	6b	-0.821***	-0.728***	0.054
V-v	V-(Ab)	4	6c	-0.691***	-0.719***	-0.966***
V-a12	V-k	5	6a	-0.836***	-0.799***	-0.302*
V-a12	V-a7	5	6b	-0.841***	-0.676***	-0.459**
V-a12	V-(Ab)	5	6c	-0.494***	-0.648***	-0.581***
V-k	V-a7	6a	6b	0.754***	0.749***	0.660***
V-k	V-(Ab)	6a	6c	0.611***	0.724***	-0.008
V-a7	V-(Ab)	6a	6c	0.774***	0.980***	0.627***

(A positive value of D' indicates association between virulence alleles; negative D' indicates dissociation between virulence alleles).
Significance of D': * P > 95% ** P > 99% *** P > 99.9%

The following changes should be noted particularly. From a strong dissociation between V-v (BMV 4) and the two "Ark Royal" virulences, V-k (BMV 6a) and V-a7 (BMV 6b) in 1985 and June 1986 and indeed, for a number of years previously, the population has now shifted dramatically to a strong association between V-v and V-k and no significant association either way between V-v and V-a7. The dissociations between V-a12 (BMV 5)

and V-k and V-a7 have become weaker also, but there has been no great change in the dissociation of V-a12 and V-(Ab). Conversely, the strong association between V-k and V-(Ab) (BMV 6c) has broken down. There has therefore been a large change in the pattern of associations of virulence alleles in the mildew population.

These changes are almost entirely due to changes in frequency of a small number of phenotypes (Table 4).

Table 4 Frequencies of important pathogen phenotypes

Type	BMV 3	4	5	6a	6b	6c	% of sample JL85	JU86	OC86
A	A	A	A	A	V	V	4.0	12.3	2.7
B	A	A	A	V	V	V	12.1	16.4	10.3
C	V	A	A	V	V	V	48.5	18.4	7.6
D	A	V	V	V	V	A	0.0	0.4	34.5
E	A or V	A	V	A	A	A	5.1	18.0	13.5
F	A or V	A	V	A	A	V	9.1	5.7	1.6
G	A or V	A	V	A	V	V	1.0	5.7	7.6

Alleles : A - avirulent V - virulent

In this period, isolates virulent on Triumph (BMR 6b+c) but not Natasha (BMR 5 + 6c) (phenotypes A, B and C) have become less common, while those virulent on both Natasha and Triumph (phenotype G) have become more common, which shows the potential for an increase in frequency of a pathogen phenotype which matches a new combination of old resistance genes. Interestingly, it can be seen in Table 3 that the dissociation between BMV 5 and BMV 6c has not broken down, although Natasha has been widely grown. In detached seedling leaf tests, the Ml-(Ab) gene in Natasha is not strongly expressed. If this is also true for the variety when grown in the field, Natasha could be selecting isolates which are BMV 5, (phenotypes D and E), but less strongly those which are BMV 5 + 6c (phenotypes F and G). There has indeed been a substantial increase in the frequency of BMV 5 (Table 2).

The most significant change, however, has been a massive increase in isolates with phenotype D, which now form 35% of the mildew population (confidence interval 27% to 43%). These are virulent on Klaxon (BMR 4 + 6a) and Doublet (BMR 4 + 6b). The new common phenotype D may also be classified as semi-virulent on Natasha, as it has BMV 5 but not BMV 6c.

These changes in the composition of the mildew population mirror changes in the spring barley varieties grown in the U.K. (Table 5). Given that phenotype D was not at all common in June 1986, some explanation is required of how it reached such a high frequency in October. One possibility is that, since the summer mildew epidemic began rather late in 1986, there may have been heavy infection on volunteers of spring barley, but not on winter barley volunteers. The mildew population which infected the autumn sowing of winter barley, which contains few race-specific resistance genes, is therefore likely to have been similar to the infection in spring barley fields earlier in 1986. This may explain the rapid increase in the frequency of phenotype D, virulent on Klaxon, Doublet and Natasha.

The rapid adaptation of the mildew population to the varieties Klaxon, Doublet and Natasha gives no grounds for confidence that the resistance of

Table 5 % of royalty bearing sales of seed of important spring barley varieties (A.S.I., 1986)

Variety	Resistance genes	1984	1985	1986
Atem	Ml-v + ml-o	14	20	22
Golden Promise	Ml-a8 ?	20	11	9
Klaxon	Ml-v + Ml-k	1	3	10
Kym	Ml-v + Ml-k + Ml-a9	6	6	3
Natasha	Mla12 + Ml-(Ab)	0	1	10
Patty	Ml-g + Ml-a12	5	4	1
Triumph	Ml-a7 + Ml-(Ab)	40	38	29

a variety which has a new combination of old resistance genes - a combination which may allow the variety to perform well initially in trials - will be durable. Although Natasha has not strongly selected BMV 5 + 6c isolates, this is probably due to the variety's weak expression of Ml-(Ab); BMV 5 isolates have been selected, as have BMV 5 + 6b + 6c isolates, virulent on both Natasha and Triumph. Klaxon, Doublet and Natasha together have, however, selected a race which is virulent on all three varieties, with a new combination of several virulence genes which were previously strongly associated. The appearance of phenotype D seriously weakens the value of several cultivars with previously effective combinations of resistance genes. Phenotype D is also likely to make it more difficult to plan effective diversification schemes or variety mixtures.

The increase in phenotypes of the pathogen with multiple virulence also increases the number of spores which are able to infect varieties which have one of the matching resistance genes alone. (Wolfe and Barrett, 1976). This means that those varieties with one of these genes alone, such at Golf (BMR 4) and Patty (BMR 5) will also become more susceptible as the complex phenotype of the pathogen increases in frequency.

These results suggest that the use of new combinations of old resistance genes is not a long-term strategy for the control of barley powdery mildew. Given that there are very few new resistance genes in new widely-cultivated varieties, and given the problems with insensitivity to more than one fungicide (Wolfe et al. 1987), the results presented here suggest that the introduction of new resistance genes and combinations of resistance genes needs to be more effectively managed to increase their usefulness.

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YELLOW RUST OF BARLEY

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The incidence of yellow rust of barley was extremely low nationally in 1986 and no samples were received by the Survey. For this reason no report is submitted.

BROWN RUST OF BARLEY

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Two new virulence combinations were detected from the 30 isolates of Puccinia hordei Otth. Both of these combine BRV-3 with the Triumph virulence. The more widely virulent one (Octal 1677) overcomes all the resistant genes in the current set of differential cultivars with the exception of Pa_7 (Cebada Capa). Cultivar Medallion was the only winter barley to express resistance to the two races carrying the Triumph virulence in field isolation nurseries. Comparisons between the three nurseries allowed identification of specific resistances in commercial spring cultivars. Cultivars Simon (BRR-3) and Corniche were resistant to all three isolates.

GLASSHOUSE SEEDLING TESTS WITH 1986 ISOLATES

Samples of barley brown rust were received from 48 winter and three spring barley cultivars during 1986. Thirty-one of these were from a trial site at SCRI, Dundee. Isolates were made from 30 of the leaf samples, the remainder failed to sporulate after inoculation onto seedlings of the universally susceptible cv. Midas. Seedling tests were carried out on each isolate to determine the presence of virulence factors compatible with the specific resistances identified in the current set of 10 differential cultivars (Table 1). In addition, the winter barley cv. Medallion was included in all tests.

Table 1. Barley genotypes used to identify virulence factors in Puccinia hordei and their ranking for octal notation

Cultivar	BBR factor	Gene symbol	Ranking for octal notation
Sudan	1	Pa	1
Peruvian	2	Pa_2	2
Ribari	3	Pa_3	3
Gold	4	Pa_4	4
Quinn	5	Pa_5	5
Bolivia	6	Pa_6	6
Cebada Capa	7	Pa_7	7
Egypt 4	8	Pa_8	8
C.I. 1243	9	Pa_9	9
Triumph	10	$Pa_?$	10

Results

The virulence combinations identified in the 30 isolates and their octal designations are given in Table 2.

Table 2. Races identified from 1986 isolates

Number of isolates	Octal designation	BRV factors
12	1673	1,2,4,5,6,8,9,10
6	1653	1,2,4,6,8,9,10
6	673	1,2,4,5,6,8,9
4	1657	1,2,3,4,6,8,9,10
1	1677	1,2,3,4,5,6,8,9,10
1	677	1,2,3,4,5,6,8,9

Virulence to the differential cv. Ribari (BRR 3) was detected in six of the nine isolates tested from the spring barley leaf samples received from a trial site at SCRI, Dundee; a fully compatible reaction to this resistance gene (Pa_3) has not been detected since 1977. Isolates cultured from samples of the winter barley cultivars grown at the same site failed to overcome this resistance. Five of the isolates combined this virulence (BRV 3) with the Triumph virulence (BRV 10) and this is the first time that this virulence combination has been detected. One isolate, BRS-86-34, from cv. Delta combines all the known virulences in the UK population, failing only to overcome the resistance of the differential cv. Cebada Capa (Pa_7). Octal race 1673 was the most prevalent race (40%) identified in 1986 as it was in 1985 (57%). Cultivar Medallion was susceptible to all isolates in these seedling tests but it has resistance that is expressed at the adult plant stage (see below).

ADULT PLANT FIELD TESTS

Twenty-three winter and 24 spring barley cultivars were sown in each of two nurseries and a third nursery was sown with spring cultivars. Also included in one of the nurseries were seven winter barley breeding lines from the Plant Breeding Institute, Cambridge. The nurseries were inoculated with one of the three following isolates of P.hordei.

1. Octal race 1673 BRV-1,2,4,5,6,8,9,10
2. Octal race 1653 BRV-1,2,4,6,8,9,10
3. Octal race 11 BRV-1,4

Octal race 11 was introduced into the nursery sown with spring cultivars only, as previous results had shown that the winter barley cultivars were all resistant to this simple race.

Results

Reasonably high levels of infection developed on the susceptible cultivars within each of the nurseries by the end of the season. Higher levels of brown rust were noted on the winter cultivars inoculated with octal race 1653, whilst the susceptible spring cultivars within the nursery inoculated with octal race 11 showed greater levels of infection than those same cultivars in the other two nurseries. Results are summarised in Table 3 (winter cvs) and Table 4 (spring cvs). All winter

cultivars were susceptible to octal race 1653 and 1673. A range of quantitative responses was noted on the cultivars, particularly within the nursery inoculated with octal race 1653 which had higher levels of disease. Cultivar Medallion again expressed a high level of resistance at the adult plant stage of growth, showing infection of a mixed reaction type.

The spring barley cultivars tested were placed into groups on the basis of specific interactions between isolates and cultivars and on previous years' results. Cultivar Simon (BRR-3) was resistant to the three isolates, none of which carries the corresponding virulence factor BRV-3. Cultivar Corniche was also resistant to all isolates, giving a low level of infection of a mostly resistant reaction type. This cultivar was resistant to octal race 677 in 1985 tests which suggests that it carries some unspecified resistance. Another group includes those cultivars with the cv. Triumph resistance (BRR-10) which is effective against octal race 11 (BRV-1,4) but not octal races 1653 and 1673, which carry BRV-10.

A similar pattern of response to cv. Triumph was shown by another group of cultivars which includes Armelle, but previous results (Jones & Clifford, 1986) suggest that these have a resistance different from cv. Triumph. The low level of infection and moderately susceptible reaction type typical of the non-specific resistance of cv. Vada was also shown by cvs Cameo and Kym and less strongly by cvs Digger, Atem and Ayr suggesting that they have resistance factors in common with cv. Vada. Cultivars Apex and Patty showed a mixed susceptible response to octal races 11 and 1673 but were resistant to race 1653 and may therefore possess BRR-5 present in the differential cv. Quinn, the corresponding virulence not being carried by this isolate. Cultivar Auto was resistant to all three isolates but gave a low level (3%) of an S-reaction type to race 1673. More tests will be required to fully characterise these latter three cultivars.

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Table 3. Response of Winter Barley Cultivars to Barley Brown Rust in Isolation Nurseries, 1986

Cultivar	Isolates: Octal race 1653 BRV-1,2,4,6,8,9,10	Isolates: Octal race 1673 BRV-1,2,4,5,6,8,9,10
Igri	18*	5
Flamenco	17	8
Kaskade	16	9
Tipper	15	5
Mallard	15	4
Marinka	14	6
Concert	13	6
Magie	13	4
Vixen	12	7
Panda	12	6
Sonja	11	5
Otter	11	4
Gerbel	10	6
Pipkin	9	7
Torrent	9	6
Sonate	8	4
Nevada	8	3
Jennifer	8	2
Pirate	5	6
Halycon	5	6
Fallon	5	3
Opera	5	2 MS
Medallion	1 MS	3 MS
CWB 193-52-1	-	7
CWB 240-187-5	-	6
CWB 240-331-4	-	5
CWB 240-4-1-1	-	5
CWB 312-81-3	-	5
CWB 195-309-3	-	4
CWB 131-5-1	-	2

*% infection for $\bar{x}$ of 4 replicates at 3 assessment dates
All reaction types susceptible unless stated. MS = Mixed susceptible

Table 4. Responses of Spring Barley Cultivars to Barley Brown Rust in Isolation Nurseries, 1986

Cultivar	Isolates: Octal race 1653 BRV-1,2,4,6,8,9,10 %	R.T.	Octal race 1673 BRV-1,2,4,5,6,8,9,10 %	R.T.	Octal race 11 BRV-1,4 %	R.T.
Midas (BRR-0)	17	S	13	S	30	S
Golden Promise (BRR-0)	19	S	11	S	25	S
Doublet (BRR-10)	14	S	7	S	1	R
Natasha	13	S	9	S	2	MR
Kingpin	13	S	7	S	3	MR
Everest	11	S	7	S	0.5	MR
Triumph	10	S	9	S	0.1	MR
Blenheim	18	S	11	S	4	MR
Dandy	11	S	8	S	6	R
Regatta	8	S	6	S	3	R
Klaxon	5	S	4	S	3	R
Vista	4	MS	3	MS	5	R
Armelle	4	S	3	S	3	MR
Simon (BRR-3)	0		0		0	
Corniche	0.5	MR	2	MR	0.5	R
Vada (BRR-Va)	1	MS	3	MS	8	MS
Digger	10	S	9	S	10	S
Atem	9	S	10	S	21	S
Ayr	6	MS	6	S	11	MS
Cameo	6	MS	7	MS	11	MS
Kym	5	MS	6	MS	12	MS
Apex	3	MR	4	MS	10	MS
Patty	2	MR	3	MS	7	MS
Auto (BRR-5)	3	MR	3	S	5	R

% = $\bar{x}$ of 4 replicates at 2 assessment dates
RT = Reaction type; S = Susceptible; R = Resistant;
MS = Mixed susceptible; MR = Mixed resistant

RHYNCHOSPORIUM OF BARLEY

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No new virulence combinations were identified from the 73 isolates of Rhynchosporium secalis tested on seedlings in 1986. Virulence to cvs Pipkin (BRR-5) and Osiris (BRR-6) was not detected, whilst the resistance of cv. Digger remained effective to all isolates. Field isolation nurseries confirmed virulence to cv. Osiris (BRR-6) in isolate Rs-85-50. This isolate also gave higher levels of infection on cvs Corgi and La Mesita both of which carry the same resistance gene (Rh^4). The Rhynchosporium survey has contributed to a joint project between Ciba-Geigy and Long Ashton Research Station to evaluate sensitivity to propiconazole and other EBI fungicides.

SEEDLING TESTS WITH 1986 ISOLATES

The generally wet summer of 1986, conducive to the development of Rhynchosporium, resulted in the large number of 160 samples being received. The infected leaf samples came from a wide range of 82 winter and 78 spring cultivars, the geographic origins of which are given in Table 1. Seventy-three isolates were successfully cultured and tested on the current set of differential cultivars and additional winter and spring cultivars. Test cultivars and their resistance factors are given in Table 2.

Table 1. Geographic origin of Rhynchosporium samples received in 1986

Geographic origin	Number of samples
Wales	53
Scotland	28
Eire	10
England (ADAS Region)	
East	35
North	18
West-central	11
East-central	4
South-west	1
Total	160

Table 2. Differential test cultivars for Rhynchosporium secalis

Resistant factor	Cultivar
BRR-0	Maris Mink
BRR-1	Armelle
BRR-2	Astrix
BRR-3	Athene
BRR-4	Igri
BRR-5	La Mesita
BRR-6	Osiris
BRR-7	Pirate

Results

The isolates, when classified by their reaction on the differential cultivars, gave a range of different, known virulence combinations. Each virulence combination identified has been designated an octal virulence number (Jones & Clifford, 1984) (Table 3).

Table 3. Virulence factor combinations identified from the 1986 survey

No. of isolates	Differential cultivars in fixed linear order							Octal virulence designation
	Pirate	Osiris	La Mesita	Igri	Athene	Astrix	Armelle	
28	0	0	0	0	0	0	0	0
16	0	0	0	1	1	1	1	17
14	1	0	0	1	1	1	1	117
7	0	0	0	1	1	0	0	14
6	0	0	0	1	0	0	0	10
2	1	0	0	1	1	0	0	114

All virulence combinations had been identified in previous years. Octal race 0, which is avirulent on all R-gene carriers (28 isolates), was the most common. Other frequently occurring combinations were octal race 17 (16 isolates) which is virulent on cvs Igri, Athene, Astrix and Armelle, and octal race 117, which is similar but carries additional virulence to cv. Pirate. It should be emphasised that these are seedling reactions and cvs Igri and Pirate carry additional adult plant resistance which appears to remain effective in the field. Virulence to BRR-6 (cv. Osiris) which was found in one isolate in 1985 was not detected in 1986. The winter cvs Halcyon, Flamenco, Opera and Marinka which were included in the seedling tests were resistant to all isolates except races 17 and 117 suggesting that they carry BRR-1 or BRR-2. Cultivars Pipkin (BRR-5) and Digger were resistant to all isolates.

ADULT PLANT FIELD TESTS IN ISOLATION NURSERIES

Three nurseries comprising 26 winter and 26 spring cultivars were sown in the 1985-86 season using standard procedures. An additional 7 winter barleys from the Plant Breeding Institute, Cambridge were included in two of the nuseries. The nurseries were each inoculated with one of the following isolates.

Table 4. Isolates used in field tests in 1986

UK CPV Code	Virulence characteristics	Octal designation
Rs-85-98	BRV-1,2,3,4	17
Rs-85-50	BRV-1,2,3,4,5,6	77
Rs-86-97	BRV-0	0

One of the nurseries was grown alongside the Rhynchosporium disease screening nursery into which octal race 0 is introduced annually. Leaf samples taken from the nursery during July 1986 and subsequently tested on seedlings of the standard set of differential cultivars identified the isolate, Rs-86-97, as being octal race 0, although low levels of infection (5%) were recorded on the cvs. Athene, Igri and Pirate.

Results

The results are summarised in Table 5 (winter cultivars) and Table 6 (spring cultivars). Reasonable levels of infection were achieved on the susceptible cultivars within the three nurseries. Leaf samples taken from the individual nurseries towards the end of the season and tested on the standard set of seedling differential cultivars, indicated that the introduced isolates had remained pure throughout the season. Cultivar Pipkin (BRR-5) which is resistant to isolates Rs-86-97 and Rs-85-98 at the seedling stage showed relatively high levels of infection within all the nurseries. This pattern of response, whereby the cultivar becomes more susceptible on the upper leaves has been observed previously with the spring cv. La Mesita, the donor of resistance in cv. Pipkin (Clifford & Jones, 1982). Cultivars Halcyon, Marinka, Opera and Flamenco showed low levels of infection within the nursery inoculated with isolate Rs-86-97 (BRV-0), probably due to the contamination noted above. Within the spring cultivars, La Mesita (BRR-5) and Corgi (BRR-5), although susceptible to all isolates on the upper leaves, showed higher levels of disease in the nursery inoculated with isolate Rs-85-50 (BRV-1,2,3,4, 5,6). Cultivar Osiris (BRR-6) was also susceptible to this isolate, confirming 1985 seedling tests when BRV-6 was detected for the first time in the United Kingdom. Cultivar Digger remained resistant suggesting that it carries a different resistance gene. The spring differential cv. Armelle (BRR-1) again expressed its high level of resistance at the adult plant stage to isolates carrying corresponding virulence genes.

FUNGICIDE INSENSITIVITY

A cooperative project between Ciba-Geigy and Long Ashton Research Station is aimed at evaluating sensitivity of R.secalis to propiconazole and other EBI fungicides. The Rhynchosporium survey at WPBS is contributing to this project by determining the relationships between variation in response to fungicides and that for host plant resistance.

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Table 5. Percent infection* of winter barley cultivars in Rhynchosporium isolation nurseries, 1986

Cultivar	Isolate Rs-86-97 BRV-0	Rs-85-98 BRV-1,2,3,4	Rs-85-50 BRV-1,2,3,4,5,6
Maris Otter	17	28	12
Medallion	15	23	14
Sonate	11	10	10
Pipkin	10	36	17
Vixen	7	23	21
Panda	6	10	5
Tipper	6	16	8
Nevada	6	8	8
Athene	6	17	14
Astrix	6	11	7
Magie	5	7	4
Mallard	4	6	8
Jennifer	4	7	5
Sonja	4	6	6
Igri	4	7	4
Kaskade	3	8	10
Flamenco	3	5	5
Mallard	3	5	3
Halcyon	2	8	3
Concert	2	5	2
Gerbel	1	6	4
Pirate	1	6	2
Marinka	1	7	5
Torrent	1	5	2
Hoppel	1	4	1
Opera	1	4	4
CWB 131-5-1	-	16	24
CWB 240-331-4	-	10	4
CWB 240-187-5	-	9	4
CWB 193-52-1	-	9	11
CWB 312-81-3	-	7	13
CWB 240-4-1-1	-	5	3
CWB 195-309-3	-	4	3

*$\bar{x}$ of 2 scoring dates, 4 replicates

Table 6. Percent infection* of spring barley cultivars in Rhynchosporium isolation nurseries - 1986

Cultivar	Isolate Rs-86-97 BRV-0	Rs-85-98 BRV-1,2,3,4	Rs-85-50 BRV-1,2,3,4,5,6
Doublet	29	5	15
Cameo	28	9	20
Kym	26	7	11
Natasha	24	5	13
Kingpin	22	10	13
Golden Promise	21	5	10
Corniche	19	6	12
Patty	18	5	16
Ayr	16	7	13
Regatta	14	7	16
Everest	14	6	12
Klaxon	14	5	9
Auto	14	5	14
Atem	13	6	11
Midas	11	5	12
Vista	11	5	8
Triumph	11	4	7
Blenheim	10	9	18
Dandy	8	4	12
Proctor	8	3	5
La Mesita	6	7	35
Apex	5	8	13
Corgi	4	3	17
Armelle	1	2	2
Osiris	0	1	11
Digger	0	1	1

*Rs-86-97 = $\bar{x}$ of 3 scoring dates, 4 replicates
Rs-85-50 = $\bar{x}$ of 2 scoring dates, 4 replicates
Rs-85-98

NET BLOTCH OF BARLEY

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Virulence to 8 of 13 differential cultivars was detected in the 28 isolates of Pyrenophora teres Drechs. tested on seedlings. Isolates carried between 1 and 7 specific virulences in various combinations. Within the spring differential cultivars no virulence compatible with the specific resistances of C.I. 5401, C.I. 4795, C.I. 4502 and C.I. 9214 was found. The winter barley cv. Code 65 was also resistant to all isolates as was cv. Marinka. Low levels of net blotch within the two isolation nurseries rendered results difficult to interpret. A few of the spring cultivars, notably Corniche, appeared to be more susceptible to the 'spotting' isolate.

GLASSHOUSE SEEDLING TESTS WITH 1986 ISOLATES

Of the 42 samples of net blotch received 38 were from winter barley cultivars and 4 from spring cultivars. The geographical origin of the samples was:

Location		No. of samples
England (ADAS Region)	East	19
	West Central	10
	South-West	1
Wales		2

The isolates of Pyrenophora teres Drechs. were inoculated onto seedlings of 13 differential cultivars plus eight additional winter cultivars, using procedures described previously (Clifford & Jones, 1981).

Results

Twenty-eight isolates were successfully tested. The frequencies of individual virulences corresponding to resistance factors in the 13 differential cultivars together with virulence frequencies over the period 1983-1985 are given in Table 1.

The spring cultivars C.I. 5401, C.I. 9820, C.I. 4795, C.I. 4502 and C.I. 9214 gave low frequencies of corresponding virulences confirming their value for inclusion in breeding programmes. The higher frequencies of virulence to C.I. 9820 and C.I. 5401 in 1985 compared to their 1986 values, was due to a batch of 1985 isolates displaying spotting symptoms, which give a more susceptible reaction on these two cultivars. Of the three winter lines, C.I. 9518 was again susceptible to a high proportion of the isolates whilst Code 65 was resistant to all isolates tested.

Table 1. Virulence frequency (%) corresponding to each differential cultivar (UK CPV Surveys 1983-1986)

Code number	Cultivar	1983	1984	1985	1986	Mean
1	C.I. 5401	0	0	14*	0	4
2	C.I. 6311	0	22	21	39	21
3	C.I. 9820	0	0	56*	4	15
4	C.I. 739	24	33	33	61	38
5	C.I. 1243	0	44	42	57	36
6	C.I. 4795	0	0	0	0	0
7	C.I. 4502	0	0	0	0	0
8	C.I. 4979	0	44	33	50	32
9	Proctor	52	55	90	79	69
10	Code 65 (W)	19	0	7	0	7
11	C.I. 9518 (W)	90	100	90	96	94
12	Tenn. 61-119 (W)	19	44	33	57	38
13	C.I. 9214	9	0	0	0	0
No. of isolates tested		21	9	15	28	

(W) = Winter cv.; *'spotting' isolates.

The virulences identified occurred in various combinations in the different isolates. The virulence combinations, designated according to the corresponding differential code numbers (Table 1) gave a range from the single virulence factor BNV-11 to the more complex and widely virulent BNV-2, 4, 5, 8, 9, 11, 12 (Table 2).

Table 2. Virulence combinations and their frequencies (1986 isolates)

Virulence combination BNV-	Number of isolates
11	4
3,11	1
9,11	1
5,9,11	1
9,11,12	3
4,9,11,12	2
4,5,8,11	1
5,8,9,12	1
2,4,5,9,11	2
2,4,5,8,9,11	2
4,5,8,9,11,12	3
2,4,5,8,9,11,12	7

The frequency of virulence to the additional 8 winter barleys included in the tests was high, although cvs Pirate, Gerbel and Pipkin did express a resistant reaction to some of the isolates. Cultivar Marinka, as in 1985, was resistant to all isolates.

FIELD ISOLATION NURSERIES

Twenty-three winter and 21 spring cultivars were sown in each of two nurseries in 1985-1986, following standard procedures. An additional 7 winter barley cultivars from the Plant Breeding Institute, Cambridge were included in one of the nurseries. The nurseries were inoculated with one or the other of the following isolates:

Survey code	Virulence combination
BNS-80-12 (net)	7,8,9,10,11,12
BNS-85-49 (spot)	1,3,5,9,11,12

Results

The cultivars were assessed throughout the season on the percentage leaf area infected. Results are given in Table 3 for winter cultivars and 4 for the springs. Disease was, as in previous years, slow to build up. Assessments on the winter barley were therefore, made late in the season and low levels of percentage leaf area infected were recorded. The cultivars inoculated with the netting isolate did, however, show a similar trend in susceptibility as in previous years, with cvs Concert, Sonja and Flamenco being amongst the most heavily infected.

The spring cultivars showed a similar order of responses to the individual isolates with the exception of cv. Corniche which was more susceptible to the 'spotting' isolate. Other cultivars, notably Triumph, Vista, Natasha, Dandy, Patty and Regatta were also more susceptible to the 'spotting' isolate. It is of interest to note that cvs Corniche and Triumph both originate from the GDR breeder, VEB which suggests a common germplasm base. As Triumph has been widely used as a parent, strains of the 'spotting' form P.teres f. maculata need to be carefully monitored in UK agriculture. The trend of an inverse relationship between susceptibility to one form and resistance to the other which had been noted previously (Clifford & Jones, 1985) was less obvious in 1986.

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Table 3. Reaction of winter barley cultivars to spotting and netting forms of Pyrenephora teres in field nurseries in 1986

Cultivar	Netting form[1] (BNS-80-12)	Spotting form[2] (BNS-85-49)
Concert	7	2
Nevada	5	1
Flamenco	5	0
Sonja	4	2
Tipper	3	1
Panda	3	1
Igri	2	1
Sonate	2	1
Jennifer	2	0
Magie	2	0
Vixen	1	1
Torrent	1	1
Halcyon	1	1
Medallion	1	0
Marinka	1	0
Kaskade	1	0
Pipkin	1	1
Mallard	1	1
Pirate	0	1
Gerbel	0	0
Otter	0	0
Opera	0	0
Falcon	0	-
CWB 131-5-1	1	-
CWB 240-4-1-1	1	-
CWB 312-81-3	1	-
CWB 193-52-1	0	-
CWB 240-187-5	0	-
CWB 240-331-4	0	-
CWB 195-309-3	0	-

[1]Nursery BNS-80-12 % infection: $\bar{x}$ of 2 scoring dates, 4 replicates
[2]Nursery BNS-85-49 % infection: $\bar{x}$ of 1 scoring date, 4 replicates

Table 4. Reaction of spring barley cultivars to spotting and netting forms of Pyrenophora teres in field nurseries in 1986

Cultivar	Netting form[1] (BNS-80-12)	Spotting form[2] (BNS-85-49)
Blenheim	8	6
Doublet	8	5
Ayr	6	5
Digger	5	4
Everest	4	5
Triumph	3	6
Kingpin	3	3
Klaxon	3	3
Atem	3	1
Corniche	2	9
Kym	2	1
Auto	1	2
Golden Promise	1	2
Apex	1	3
Cameo	1	1
Vista	1	4
Natasha	1	4
Dandy	1	4
Patty	1	3
Regatta	1	3
Midas	1	2

BNS-80-12 % infection: $\bar{x}$ of 2 scoring dates, 4 replicates
BNS-85-49 % infection: $\bar{x}$ of 2 scoring dates, 4 replicates

MILDEW OF OATS

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Twenty-three samples were received and from these, 16 isolates were successfully cultured. The results confirmed the trend in recent years of the relatively complex race 5 (OMV 1,2,3) being the predominant virulence combination with 63% frequency. Race 3 (OMV 1,2), which is unable to attack cultivars with OMR-3 resistance, remained at the frequency level of the previous two years (c.30%). Only one isolate, sampled at the WPBS, Aberystwyth, overcame the Avena barbata (OMR 4) resistance.

Adaptation to adult plant resistance was investigated in eight spring oat cultivars using detached leaf segments, inoculation being carried out directly in the field using a suction spore-trap. There was no clear indication of adaptation in any of the mildew populations and, as in 1985, there was no suggestion of adaptation to the partial resistance of cvs Rhiannon and OM 1387.

SEEDLING TESTS WITH 1986 ISOLATES

Twenty-three leaf samples of Erysiphe graminis avenae were received in 1986, reflecting the generally low incidence of mildew. Nine were from winter oat cultivars collected at Rosemaund EHF, Herefordshire, two from spring oat cultivars sampled at Trawscoed EHF, Dyfed, and the remaining 12 were collected from winter and spring oats at WPBS. The 16 isolates which were successfully cultured were tested using methods described previously (Jones & Jones, 1980).

Results

Details of the mildew samples tested are given in Table 1, and the frequency of occurrence of the various virulences detected in 1986, as compared with the previous three years, is shown in Table 2. The predominant virulence combination in 1986, as in the previous two years, was the relatively complex OMR 1,2,3 (race 5) with a frequency of 63%. These virulence factors enable it to attack all cultivars on the 1986 and 1987 NIAB Recommended Lists of winter and spring oats. The frequency of OMV 1,2 (race 3) has maintained the same level since 1984 at around a third of the total isolates. One isolate, from a spring oat breeding line 08540 Cn IV, collected at Morfa Mawr, Dyfed, was virulent on the differential cv. Avena barbata (OMR 4). This virulence was combined with OMV 1,2,3 thus making it capable of attacking all commercial cultivars.

The simple races 2 (OMV 1) and 4 (OMV 1,3) were not detected in the 1986 samples.

Table 1. Locations and cultivars from which viable mildew samples were received with virulences identified for each sample

Location	Cultivars	Virulences (OMV)
ENGLAND		
Rosemaund, Herefordshire	Solva	1,2
	78/1 Cn 3/1	1,2,3
WALES		
Trawscoed, Dyfed	Leanda, Major	1,2
Morfa Mawr, Dyfed	07796 CN II, 07408 Cn III-I,	1,2,3
	Rhiannon, Avalanche, Rollo,	1,2,3
	08540 Cn IV	1,2,3,4
WPBS, Aberystwyth, Dyfed	Branwen, Lustre(2),	1,2,3
	76-17 Cn 22/2/3, Peniarth(2)	1,2,3

Table 2. Virulence group frequencies identified from samples received in 1986 compared with previous three years

Virulence Group	Race	Frequency (% total) 1983	1984	1985	1986	No. of isolates in 1986
OMV 1	2	15	0	0	0	0
OMV 1,2	3	77	32	37	31	5
OMV 1,3	4	0	2	0	0	0
OMV 1,2,3	5	8	64	46	63	10
OMV 1,2,4	6	0	0	4	0	0
OMV 1,2,3,4	7	0	2	13	6	1
No. of isolates tested		13	41	24	16	16

ADULT PLANT TESTS

As in previous years, tests were carried out to investigate whether adaptation was occurring in the mildew from various cultivars carrying adult plant resistance and grown under field conditions. The Schwarzbach spore-trap was used to collect spores from field plots of cvs Selma, Avalanche, Rhiannon, Rollo, Dakota, 07796 Cn, 07408 Cn, and OM 1387 on 16 June 1986. The breeding line OM 1387 has no major genes for resistance, but has a high level of partial resistance. The lines 07796 Cn, and 07408 Cn III/1 were both advanced lines undergoing trials in the WPBS spring oat breeding programme. These and the other named cultivars carry known specific resistances (see Table 3).

The spores were deposited on detached, mildew-free leaf segments of the eight cultivars, which had been grown in a spore-proofed glasshouse. The segments, cut from the Flag-2 leaves of the test cultivars were placed on Benzimidazole Agar in polystyrene boxes which were inserted into the base of the spore-trap for each collection. Each box contained two randomised

blocks of the eight test cultivars and two boxes (total of four blocks) were used for each inoculum source. The inoculated leaf segments were incubated in a controlled environment of 10 ± 2°C and 12 h photoperiod. The percentage leaf segment area showing mildew was recorded after ten days. Further details of the method used are given in Jones & Jones (1984).

Results

Mean values for percentage leaf area infected with mildew are given in Table 3 and means after analysis of variance of the logit transformation of the original values are given in Table 4. All LSD values are given at P = 0.05 level of probability unless otherwise stated.

Selma, a highly susceptible cultivar with no known hypersensitive race-specific resistance (OMR 0) was used as a control. It showed generally high levels of mildew relative to the other test cultivars, its overall mean value of 20.8% (Table 3) being significantly higher (Table 4) than the other cultivars except for cvs Rollo (15.4%) and 07796 Cn (17.4%). Selma was also the most susceptible cultivar in the 1984 tests when segments were taken from leaves below the flag leaf. In 1985, when the flag leaf was used, cv. Selma gave a more resistant response. The 1986 results therefore, supports last year's observation that a resistance factor with small effect becomes effective in the flag leaf of cv. Selma (Jones, 1986).

As in 1985, the overall means of Rhiannon (0.2%), a naked oat, and OM 1387 (0.1%) were significantly lower (Table 4) than any of the other cultivars. These two cultivars were resistant to all isolates except the one sampled from the plot of 07408 Cn III/1, when very low levels of infection were recorded. The isolate sampled from 07408 Cn III/1 appears to be more aggressive than the other isolates with an overall inoculum source mean of 18.3% (Table 3). This value is significantly higher than the means of the other isolates, with the possible exception of cvs Dakota, 07796 Cn and Rollo (Table 4).

Cultivar Rhiannon has shown high levels of resistance to all isolates tested by this method since 1983, including those possessing virulence to its major gene resistance OMR 3. Only one isolate from a field plot of cv. Rhiannon in 1984 has indicated any possible adaptation to the adult plant resistance of this cultivar which is additional to its hypersensitive overall resistance (OMR 3) (Jones & Jones, 1985). The other OMR 3 cultivars, Avalanche, Dakota and 07408 Cn III/1 would be expected to show similar levels of infection when inoculated with isolates from the other OMR 3 cultivars, unless they carried additional resistance. With cv. Avalanche, however, the isolate from Rhiannon produced no infection whereas the other isolates sampled from OMV 3 cultivars gave fairly high levels of mildew on this cultivar. There is no clear explanation for this other than that the mildew sampled from cv. Rhiannon, which was less abundant than that sampled from the other cultivars (see Table 3), lacks a virulence factor present in the other isolates, and which is required to overcome additional resistance factors in cv. Avalanche.

Adaptation is measured by comparing the 'own host' infection values (underlined in Tables 3 and 4) with the values for that cultivar

Table 3. Percentage leaf area infected with mildew on detached leaf segments of the flag-2 leaves of eight test cultivars (means of four blocks)

Test cultivars		Inoculum source (isolates) Selma (OMR 0)	Selma (OMR 3)	Avalanche (OMR 3)	Rhiannon (OMR 2)	Rollo (OMR 3)	Dakota (OMR2?)	07796 Cn (OMR 3)	07408 Cn (OMR 0)	OM 1387 Mean
Selma	(OMR 0)	12.0	29.0	5.5	16.5	29.0	27.5	25.0	22.5	20.8
Avalanche	(OMR 3)	3.0	16.5	0	15.0	11.5	9.0	21.0	12.5	11.0
Rhiannon	(OMR 3)	0	0	0	0	0	0	1.5	0	0.2
Rollo	(OMR 2)	12.5	5.0	7.5	16.0	19.0	26.5	26.5	11.5	15.4
Dakota	(OMR 3)	5.5	15.0	9.0	15.0	11.5	20.0	17.0	14.0	13.2
07796 Cn	(OMR 2?)	11.0	17.5	10.0	14.0	15.0	14.5	35.0	23.0	17.4
07408 Cn	(OMR 3)	1.5	11.0	9.0	15.0	22.5	19.0	20.0	4.0	12.7
OM 1387	(OMR 0)	0	0	0	0	0.2	0	1.0	0	0.1
Mean		5.6	11.6	5.0	11.3	13.4	14.5	18.3	10.9	11.3

Mean of 8 'own host' or homologous underlined means = 11.3; Mean of 56 'other' or heterologous means = 11.4

Table 4. Percentage leaf area infected with mildew (x) on detached segments of the flag-2 leaves of eight test cultivars (means of four blocks) (Logit transformation x + 0.1)

Test cultivars		Inoculum source (isolates) Selma (OMR 0)	Avalanche (OMR 3)	Rhiannon (OMR 3)	Rollo (OMR 3)	Dakota (OMR 3)	07796 Cn (OMR 2?)	07408 Cn (OMR 3)	OM 1387 (OMR 0)	Mean (LSD=±0.618)
Selma	(OMR 0)	-2.38	-1.04	-3.78	-1.78	-1.15	-0.98	-1.20	-1.35	-1.71
Avalanche	(OMR 3)	-3.51	-1.89	-6.91	-1.89	-3.05	-2.72	-1.85	-2.09	-2.99
Rhiannon	(OMR 3)	-6.91	-6.91	-6.91	-6.91	-6.91	-6.91	-5.91	-6.91	-6.79
Rollo	(OMR 2)	-2.22	-3.27	-3.53	-1.79	-1.53	-1.19	-1.07	-2.56	-2.15
Dakota	(OMR 3)	-4.01	-2.48	-3.32	-2.05	-2.14	-1.45	-1.84	-1.84	-2.39
07796 Cn	(OMR 2?)	-2.37	-1.78	-2.53	-1.97	-1.89	-1.99	-0.66	-1.65	-1.86
07408 Cn	(OMR 3)	-5.31	-3.11	-4.39	-1.80	-1.30	-2.55	-1.61	-4.13	-3.01
OM 1387	(OMR 0)	-6.91	-6.91	-6.91	-6.91	-6.91	-6.91	-5.54	-6.91	-6.75
Mean (LSD=±0.618)		-4.20	-3.42	-4.79	-3.14	-3.11	-3.09	-2.53	-3.43	-3.46

LSD to compare inoculum source/test cultivar means
= ±1.75 (P = 0.05), ±2.30 (P = 0.01), ±2.94 (P = 0.001)

Mean of 8 'own host' or homologous underlined means = -3.20 ± 0.22 (n = 32);
Mean of 56 'other' or heterologous means = -3.49 ± 0.08 (n = 224); DF to test difference = 187

inoculated with the 'other host' isolates (i.e. values in the same row). The 'own host' values for cvs Selma, Rhiannon, Rollo, Dakota, 07796 Cn and OM 1387 are not significantly higher than for other values in their respective rows, thus there is no evidence of adaptation within these mildew populations. The value of the 'own host' isolate of 16.5% (Table 3) for Avalanche, is only significantly higher than the value for the isolate from cv. Rhiannon (Table 4) thus confirming its higher level of partial resistance compared with other OMR 3 cultivars included in the test. Mildew from 07408 Cn III/I gave a significantly higher infection (20%) on its own host than did isolates from Selma (1.5%), OM 1387 (4%) and Rhiannon (9%). This suggests that mildew from cv. Selma (OMR 0) carries OMV 3 at only a low frequency and this is supported by the fact that the other OMR 3 cultivars inoculated with isolates from this cultivar also gave low levels of infection. Cultivar 07408 Cn may have an additional factor(s) which is overcome by the mildew sampled from this cultivar. Mildew sampled from cv. OM 1387 appears to lack this virulence thus accounting for the low level (4.0%) of infection recorded.

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CROWN RUST OF OATS

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Only one sample of oat crown rust from the spring oat cv. Rollo was received in 1986 from Devon. An isolate of *Puccinia coronata* was cultured from the leaf sample. Seedling tests on the 10 differential cultivars identified the isolate, CRS-86-1, as being race 251. This virulence combination is compatible with the differential cvs Appler, Bond and Saia and occurs commonly in the UK.

VARIETY DIVERSIFICATION SCHEMES FOR WINTER WHEAT AND WINTER AND SPRING BARLEY, 1987

Variety diversification schemes to reduce the spread of disease in winter wheat and spring barley have been produced by the UKCPVS Committee since 1975. This year, for the first time, the barley scheme has been expanded to include both winter and spring varieties. The two schemes which follow update those in the last Annual Report.

The schemes are used to encourage farmers to grow a number of varieties possessing different specific resistances either in adjacent fields or in the same field as a variety mixture. Disease is unlikely to spread between varieties possessing different specific resistances because spores generated on one variety are largely non-virulent on the other.

The general principle and history of the UK diversification schemes has been described by Priestley and Bayles (1980). Evidence that the schemes are effective in reducing the spread of disease has been summarised by Priestley and Bayles (1982) and the use of cultivar mixtures as a method of disease control has been reviewed by Wolfe, Barrett & Jenkins (1981).

The schemes currently available are for yellow rust and mildew of winter wheat and for mildew of winter and spring barley. The UKCPVS has also examined the possibility of including brown rust in the wheat scheme. With current varieties, diversification for brown rust is not effective, but the position will be reviewed regularly. Varieties with good resistance to brown rust are available and should be grown in areas where there is a high risk of the disease occurring. Further details of specific resistances to brown rust in wheat varieties are given in the papers on 'Brown Rust of Wheat' in this and previous UKCPVS Annual Reports.

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VARIETAL DIVERSIFICATION SCHEME TO REDUCE SPREAD OF YELLOW RUST AND MILDEW IN WINTER WHEAT 1987

Severe infections may result if yellow rust or mildew spread between varieties which are susceptible to the same races of the pathogens. This risk is reduced if varieties with high levels of resistance are grown. Disease spread can be limited further by sowing different varieties in neighbouring fields, provided that they are not susceptible to the same races of yellow rust or mildew. The Diversification Scheme should be used to choose winter wheat varieties to grow adjacent to each other.

Choosing varieties to grow together

1) Decide upon first-choice variety and locate its Diversification Group (DG).
2) Find this DG under 'Chosen DG' down left hand side of table.
3) Read across table to find the risk of disease spread for each companion DG.
   + = low risk of spread of yellow rust or mildew
   y = risk of spread of yellow rust
   m = risk of spread of mildew

DG 1A	DG 1H	DG 3B	DG 8B	DG 13B
Brock	Mission	Longbow	Galahad	Brimstone
Fenman		Norman		
Mercia	DG 1J		DG 9B	
Parade	Hornet	DG 7D	Avalon	
		Stetson	Brigand	
	DG 1K			
DG 1E	Rendezvous	DG 7G	DG 9F	
Aquila		Slejpner	Rapier	

Chosen DG	Companion DGs: 1A	1E	1H	1J	1K	3B	7D	7G	8B	9B	9F	13B
1A	+	+	+	+	+	+	+	+	+	+	+	+
1E	+	m	m	+	+	+	+	+	+	+	m	+
1H	+	m	m	+	m	+	+	+	+	+	m	+
1J	+	+	+	m	+	m	m	m	m	m	m	m
1K	+	+	m	+	m	m	+	+	m	m	m	m
3B	+	+	+	m	m	ym	+	+	m	m	m	ym
7D	+	+	+	m	+	+	ym	+	+	+	m	+
7G	+	+	+	m	+	+	+	ym	+	+	m	+
8B	+	+	+	m	m	m	+	+	ym	m	m	m
9B	+	+	+	m	m	m	+	+	m	ym	ym	m
9F	+	m	m	m	m	m	m	m	m	ym	ym	m
13B	+	+	+	m	m	ym	+	+	m	m	m	ym

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VARIETAL DIVERSIFICATION SCHEME TO REDUCE SPREAD OF MILDEW IN BARLEY 1987

Severe infections may result if mildew spreads between varieties which are susceptible to the same race of the pathogen. This risk is reduced if varieties with high levels of resistance are grown. Spread can be limited further by sowing different varieties in neighbouring fields provided that they are not susceptible to the same races of mildew. The Diversification Scheme should be used to choose a) winter or spring barley varieties to grow adjacent to each other and b) spring barley varieties to grow adjacent to winter barley.

Choosing varieties to grow together

1) Decide upon first-choice variety and locate its Diversification Group (DG).
(W) = winter variety; (S) = spring variety
2) Find this DG number under 'Chosen DG' down left hand side of table.
3) Read across table to find the risk of mildew spread for each companion DG.
+ = low risk of spread of mildew
m = high risk of spread of mildew

DG0
Concert (W)
Fallon (W)
Gerbel (W)
Halycon (W)
Igri (W)
Jennifer (W)
Magie (W)
Mallard (W)
M. Otter (W)
Nevada (W)
Panda (W)
Pirate (W)
Tipper (W)
Torrent (W)
Vixen (W)
Corgi (S)
Golden Promise (S)

DG1
Opera (W)
Sonate (W)
Ayr (S)
Camargue (S)
Esk (S)

DG2
Apex (S)
Atem (S)
Dandy (S)

DG3
Auto (S)
Golf (S)
Goldmarker (S)

DG4
Pipkin (W)
Digger (S)
Sherpa (S)

DG5
Kaskade (W)
Blenheim (S)
Corniche (S)
Egmont (S)
Heriot (S)
Kingpin (S)
Natasha (S)
Patty (S)

DG6
Marinka (W)
Triumph (S)

DG7
Celt (S)
Delta (S)
Flute (S)
Regatta (S)
Vista (S)

DG8
Cameo (S)
Kym (S)
Tweed (S)

DG9
Doublet (S)
Everest (S)
Klaxon (S)
Tennis (S)

Chosen DG	DG 0	DG 1	DG 2	DG 3	DG 4	DG 5	DG 6	DG 7	DG 8	DG 9
DG0	m	m	m	m	m	m	m	m	m	m
DG1	m	+	+	+	+	+	+	+	+	+
DG2	m	+	m	+	+	+	+	+	+	+
DG3	m	+	+	m	+	m	+	+	m	m
DG4	m	+	+	+	m	+	+	+	+	+
DG5	m	+	+	m	+	m	m	+	+	m
DG6	m	+	+	+	+	m	m	+	+	m
DG7	m	+	+	+	+	+	+	m	+	+
DG8	m	+	+	m	+	+	+	+	m	m
DG9	m	+	+	m	+	m	m	+	m	m