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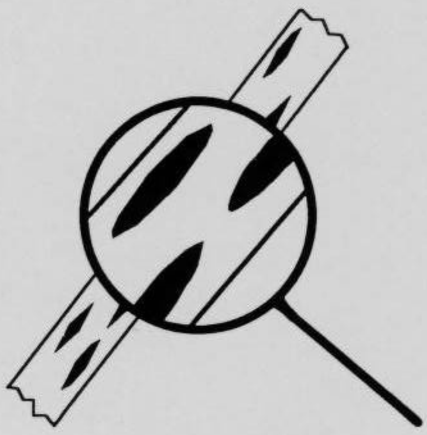
U.K. CEREAL PATHOGEN VIRULENCE SURVEY



1993 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.

OBJECTIVES

The principal objective of the survey is the early detection of increased virulence compatible with resistances 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 throughout the United Kingdom, who collect samples of infected leaves from field crops and cultivar trials and send them to the two testing centres:

- National Institute of Agricultural Botany, Cambridge, for mildew and yellow rust of wheat and barley.
- Institute for Grassland and Environmental Research, 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 such as static seedling nurseries are also used.

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 wheat and barley cultivars in diversification groups on the basis of their specific resistances. The results of the virulence tests and the diversification schemes are published in the Annual Report.

The information provided by the Survey is used in several ways. Isolates possessing new virulences are used by the National Institute of Agricultural Botany to evaluate the resistance of cereal cultivars in official trials and 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 by the National Institute of Agricultural Botany and the Scottish

Agricultural College.

The UKCPVS is funded by MAFF and HGCA, with a contribution from breeders through fees charged for National List testing.

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

Specific resistance and specific virulence

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 numbered 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 resistance are classified as RO and isolates lacking specific virulence are classified VO.

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 1993

Mildew of wheat

Virulence factors corresponding to the resistance factors in commercial wheat varieties in the UK were mostly recorded at high frequencies in 1993. The least frequent virulence factors (WMVp, q, and 'Axona'), occurring in 10-20% of isolates, were those corresponding to resistances which until recently have only been used in spring varieties. A large proportion of isolates carried three or more virulence factors enabling them to infect most winter wheat varieties on the UK Recommended List. However, many varieties have good resistance to mildew which does not depend on these specific resistance factors.

A small number of isolates of wheat mildew was tested for sensitivity to fenpropimorph. Many of the isolates were less sensitive to fenpropimorph than the control isolates, but the tests did not suggest any decrease in sensitivity when compared to similar tests carried out in 1991.

Yellow rust of wheat

The frequencies of virulences WYV 1, WYV 2, WYV 3, WYV 4, WYV 6 and WYV 9 remained high. Virulence for Talon reached 60%. Seven new varieties showed good adult plant resistance to all isolates, although differing from one another in seedling reactions.

Brown rust of wheat

Adult plant tests in field isolation nurseries inoculated with specific isolates of brown rust enabled the spring and winter wheat varieties to be grouped on the basis of similarities in their patterns of response. Seedling and adult plant tests carried out in controlled environments identified several winter wheat varieties as carrying resistance effective only at the adult plant stage of growth. Some of these resistances were temperature-sensitive. These tests identified new races of brown rust able to attack previously resistant varieties. One pathogen strain, cultured from a sample taken from Hunter, in Kent, overcame the resistance of Buster, Slejpner, Zodiac, Hunter, Hereward, Spark, Hussar and Brigadier.

Mildew of barley

Virulence factors corresponding to widely used specific resistance genes were mostly recorded at high frequencies. Virulence for BMR 9 (mlo) was not detected. The barley mildew population has maintained a high level of complexity, and in 1993 most isolates carried at least five resistance factors. For the first time, all isolates were tested for BMV 11, and this virulence factor was detected at a low frequency, even though the corresponding resistance gene (Mla3) has not been used in commercial cultivars in the UK.

In Northern Ireland, the single virulence BMV 7 increased markedly, possibly due to an increase in popularity of Chad (BMR 6c,7). Unlike in Britain, BMV 10 did not increase, while the combined virulence BMV 4,10, isolated at a very low frequency in 1992, was not isolated at all in 1993.

Barley mildew surveyed in Tayside had a higher frequency of BMV groups 4, 8 and 10 than NIAB samples but reduced frequency of BMV 6b+c and BMV 7. These differences are partly explained by the popularity of Camargue in Scotland.

A small number of isolates of barley mildew was tested for sensitivity to fenpropimorph. Many of the isolates were less sensitive than the control isolates, but when compared to tests carried out in 1991 there was no suggestion that there has been any decrease in sensitivity between 1991 and 1993. The recent trend towards resistance to Baytan seed-treatment in Northern Ireland appeared to be levelling off.

Yellow rust of barley
Only one isolate was received and this possessed the virulence combination BYV 1,2.

Brown rust of barley
Seedling tests on 18 isolates cultured from selected leaf samples identified 3 previously detected races. Within the field isolation nurseries, the winter barleys displayed a range of quantitative responses with some varieties showing good levels of resistance. Variety x pathogen interactions enabled the spring barleys to be grouped on the basis of similarities in their patterns of response.

Rhynchosporium of barley
One new race, designated Octal 74 was found in one isolate. It poses no new threat as the virulence factors carried by this isolate have previously been identified in more complex races. In field isolation nurseries, some of the winter barley varieties displayed good levels of resistance to the pathogen. The resistance of the spring barley variety Digger remains effective.

Net blotch of barley
Seedlings inoculated with isolates from the 1993 leaf samples of net blotch identified virulence factors compatible with only three of the differential varieties. Frequencies of virulence to these varieties has been at high levels in previous years. Additional winter and spring barley varieties included in the tests displayed a range of responses to the seven isolates.

Fungally-transmitted mosaic viruses of barley
Of 59 infected samples received in 1993, 56% contained barley yellow mosaic virus (BaYMV) and 54% barley mild mosaic virus (BaMMV). As in previous years, BaMMV was more frequent on malting varieties (Halcyon, Pipkin, Puffin and Sprite) whereas BaYMV predominated amongst varieties used for feed. One new "resistance-breaking" outbreak of BaYMV was reported bringing the UK total to 16.

Mildew of oats
Race 5 (OMV 1,2,3) was identified from 80% of the 35 isolates. Virulence to the resistance derived from Avena barbata (OMV-4) was detected in the remaining seven. isolates.

Crown rust of oats
Five virulence combinations were identified from the 1993 crown rust samples. Races 205 and 289 have been found at low frequencies in the pathogen population in recent years. Race 330 was last detected in 1971. A previously unidentified virulence combination, race 449, was carried by one sample. The commonly occurring race 251 was identified in the remainder.

SURVEY OF WINTER WHEAT DISEASES IN ENGLAND AND WALES 1993

W.S. CLARKE

ADAS Arable Crops Development Centre, Cambridge

From a stratified sample, 392 randomly selected crops of winter wheat were examined for foliar and stem diseases at the milky-ripe growth stage, which occurred between mid-June and mid-July. All foliar diseases were more severe nationally than in 1992, and in total were more important than at any time since 1987. However, there were considerable regional variations. *Septoria tritici* was the most severe foliar disease for the fourth consecutive year reaching the levels seen in 1987. The disease affected 4.2% of the second leaf nationally but in Wales and the south-west it was more damaging than for many years affecting respectively 15.5% and 12.7% of the second leaf. Mildew affected 0.8% of leaf 2, with the highest levels being recorded in the south-west. *Septoria nodorum* recovered slightly from the very low levels seen in recent years, affecting 0.5% of leaf 2. Brown rust affected 0.8% of leaf 2. As in previous years, this disease was most damaging in the extreme south-east, but levels in the east were higher than recorded in any survey since 1977.

14.1% of stem bases were affected by moderate or severe eyespot symptoms, the highest level recorded since 1988. In contrast, sharp eyespot, with only 1.9% of stems having moderate or severe symptoms, was less important than in any survey since 1979. Stem base fusarium was less severe compared to 1992 with moderate or severe nodal internodal symptoms occurring on 6.9% and 4.0% of stems respectively. The incidence of fusarium ear blight was similar to that found in 1992, with the disease being recorded in 17.1% of fields with 1.9% of ears affected in total. Ear blight symptoms were most frequent in the extreme south-east. Visible take-all patches were recorded in 12.5% of crops. Plants with BYDV symptoms were seen in 18.4% of crops but patches of affected plants were seen in only 3.2% of fields.

Riband was the most popular variety recorded for the third consecutive year, accounting for 39.3% of crops in the stratified survey sample. The highest level of *Septoria tritici* was recorded on Riband, and brown rust was most damaging on Haven, reflecting the NIAB disease resistance ratings of these varieties. Some diseases, particularly eyespot and take-all were affected by agronomic factors such as previous cropping and sowing date. The highest levels of brown rust were recorded in crops drilled after the end of October.

Fungicide sprays were used on 95.7% of the crops sampled. 75.0% of crops were treated with a fungicide at growth stage 31, 39.0% at growth stage 39 and 69.1% at growth stage 59, the most popular regime (24.4% of crops) being a first spray at growth stage 31 followed by a second spray at or around growth stage 59. Total fungicide usage was little changed with crops receiving, on average, 2.1 fungicide sprays each. 95.1% of crops were grown from treated seed with Cerevax, Baytan and Rappor being the most widely used products.

SURVEY OF WINTER BARLEY DISEASES IN ENGLAND AND WALES 1993

W.S. CLARKE

ADAS Arable Crops Development Centre, Cambridge

From a stratified sample, 375 randomly selected crops of winter barley were examined for foliar and stem base diseases during the watery-ripe to early milk stage in June and early July. Total foliar disease levels were higher than at any time since 1989. Brown rust was the most severe foliar disease, affecting 3.0% of the second leaf. The highest levels were recorded in East Anglia and southern districts. Net blotch was more important than at any time in the past 6 years, affecting 2.7% of the second leaf nationally, and 7.1% in the south-west, the highest level recorded there since 1981. Mildew was slightly less severe than in 1992, affecting 2.4% of leaf 2, but was more important in the north, the midlands and extreme south-east than elsewhere. Rhynchosporium nationally affected 1.4% of leaf 2, the highest level recorded for 5 years. It was particularly severe in the extreme south-west where 5.2% of the second leaf was affected.

24.6% of stem bases had moderate or severe symptoms of eyespot, almost twice the level seen in the previous year, and, with 1988, the most damaging level recorded since surveys began. Other stem base diseases, however, were less important than in 1992. Moderate or severe sharp eyespot was recorded on only 1.1% of stems, moderate or severe symptoms of nodal fusarium on 12.4% and moderate or severe internodal fusarium on 1.1%. Severe symptoms of any stem base disease were rare. 2.9% of fields had visible patches of BYDV compared to 3.3% in the previous year.

Puffin, Marinka and Pastoral were the most popular cultivars encountered, accounting for 20.3%, 19.2% and 17.6% respectively of the crops in the stratified survey sample. Brown rust was most severe on Marinka and Pastoral, net blotch on Puffin and rhynchosporium on Fighter and Pipkin. Mildew was least severe on Fighter and Halcyon, consistent with the high NIAB resistance ratings of these varieties. Mildew was more prevalent on later sown crops, and eyespot on early sown crops.

Fungicide sprays were used on 91% of crops, 10.5% of crops were treated with a fungicide spray before the end of tillering, 74.6% at growth stage 31, and 39.8% at or after growth stage 37. The most popular spray regimes were a single spray at or around growth stage 31 (41.5% of crops) and a 2-spray programme, at growth stages 31 and 37 or later (19.8% of crops). The use of prochloraz or flusilazole at growth stage 31 was associated with reduced levels of eyespot. 96.4% of crops were grown from treated seed, with Cerevax, Cerevax Extra, Ferrax and Baytan being the most widely used products.

MILDEW OF WHEAT

S E SLATER AND A G MITCHELL

National Institute of Agricultural Botany, Cambridge

Virulence factors corresponding to the resistance factors in commercial wheat cultivars in the U.K. were mostly recorded at very high frequencies in 1993, as in previous years. The least frequent virulence factors, occurring in 10-20% of isolates, were those which until recently have only been used in spring cultivars. A large proportion of the isolates carried three or more virulence factors enabling them to infect most of the winter wheat cultivars on the U.K. Recommended List.

INTRODUCTION

In recent years a high frequency of virulence factors corresponding to most of the resistance factors in wheat cultivars in the U.K. has been recorded (Mitchell & Slater 1991, 1992, 1993). In consequence, although many winter cultivars have specific resistances they now rely on partial resistance for their resistance to mildew in the field. Some newer cultivars have specific resistance factors, derived from spring wheat parents, which have not yet been widely exposed. In 1993 the survey continued to monitor the frequencies of virulence factors and combinations of these factors.

METHODS

A total of 224 samples of wheat mildew were received in 1993, mostly from trial plots at NIAB centres. Single colony isolates were taken from the infected leaves of 190 samples. The remaining 34 samples failed to produce viable isolates. The samples were collected from the following locations:

	Number of isolates		Number of isolates
Bridgets, Hants.	19	Boston, Lincs.	2
Wye, Kent	20	Grantham, Lincs.	4
Abington, Cambs.	12	Long Sutton, Lincs.	20
NIAB, Cambs.	64	Market Rasen, Lincs.	1
Thriplow, Cambs.	20	Spalding, Lincs.	39
Norfolk	4	Headley Hall, Yorks.	101
Rosemaund, Hereford & Worc.	18	Cockle Park, Northumb.	32
Total	356		

The isolates were taken from infected leaves of the following cultivars:

Winter cultivars	Number of isolates		Number of isolates
Cerco	9	Hunter	18
Hereward	7	Slejpner	2
Genesis	8	Admiral	6
Prophet	12	Apollo	5
Rialto	18	Zodiac	8
Andante	14	Brigadier	9
Norman	2	Hussar	9
Flame	21	Lynx	21
Riband	11	Mercia	5
Torfrida	1	Spark	17
Estica	6	Cadenza	20
Buster	18	Soissons	11
Beaver	15	26 cultivars of unknown resistance	51
Haven	18		
Spring cultivars	**Number of isolates**		**Number of isolates**
Alexandria	1	Concerto	1
Tonic	2	Canon	3
Axona	2	Rascal	2
Promessa	2	Scamp	1
Total	356		

The isolates were tested on detached leaves of the differential cultivars shown in Table 1 and assessed for virulence according to the infection types of Moseman *et al.* (1965).

Table 1. Differential cultivars used to determine virulence factors in wheat mildew in 1993.

WMR group	Resistance genes	Differential cultivar
0	None	Cerco
2	*Pm2*	Galahad
4	*Pm4b*	Armada
5*	*Pm5*	Hope
5*	*Mli*	Flanders
2,6	*Pm6*	Brimstone
7	*Pm8*	Clement
9	*Mld*	Maris Dove
2, 'Talent'	*Pm2*, Unknown	Brock
5, 'Talent'≠	*Pm5*, Unknown	Mercia
p	Unknown	Tonic
q	Unknown	Broom
5, r	*Pm5*, Unknown	Sicco
'Sona'	Unknown	Wembley
'Axona'	Unknown	Axona

* WMR5 *(Pm5)* and WMR8 (*Mli)* are considered to be identical (Heun & Fischbeck 1987).
≠ Mercia has previously been described as WMR8, m, but there is sufficient evidence from the survey work in 1992 and 1993 to consider WMRm as equivalent to WMR'Talent'.

RESULTS

Virulence frequencies

Table 2 shows the results of the 1993 survey, together with those of 1990, 1991 and 1992. As in previous years the frequencies of WMV2, 4, 5, 6, and 7 in 1993 were high in populations irrespective of the source cultivar. WMV2 remains at a near maximum level, while WMV5 has also maintained a high frequency. WMV4 and WMV6 showed high levels similar to 1992. The data from the last four years showed that the trend to increasing virulence corresponding to Mercia (WMR5, 'Talent') has continued, although the popularity of this cultivar is now declining. From a comparison of the reactions of isolates on Mercia and Brock it seems likely that the resistance factor previously designated 'm' in Mercia is the same as the Talent resistance. If this is so, it would explain the continued increase in the frequency of virulence for Brock (WMR2, 'Talent'), even though the area of this cultivar is now small.

Table 2. Frequency of wheat mildew virulence factors in isolates from infected leaves collected in 1990, 1991, 1992 and 1993.

	Frequency of virulence factors (%)			
Virulence factor	1990	1991	1992	1993
2	99	100	99	98
4	52	69	73	79
5	-	92	90	95
6	69	80	76	78
7	66	80	86	93
9	-	-	27	15
2, 'Talent'	-	54	60	80
5, 'Talent'	34	50	60	79
p	-	9	24	18
q	-	-	31	20
5, r	-	38	32	39
'Sona'	-	-	23	22
'Axona'	-	10	17	10
Number of isolates tested	290	300	194	356

There was also a further increase in the frequency of WMV7, reflecting the continued popularity of cultivars with WMR7, such as Beaver and Haven, and the newer cultivars Hunter, Admiral, Hussar and Brigadier.

The frequencies of WMVp, WMVq, WMVr, WMV'Sona' and WMV'Axona' do not show any definite trends. The corresponding resistance factors were previously found only in spring wheat cultivars.

All the isolates identified as WMV'Axona' in the last two years also carry WMV9. Since Maris Dove (WMR9) is one of the parents of Axona it is possible that Axona also carries

WMR9 in addition to the unknown resistance factor designated WMR'Axona'. This would explain the relatively high frequency of WMV9 in what was thought to be the absence of any commercial cultivar with the corresponding resistance.

The frequencies of the pathotypes, as defined by WMV2, 4, 5, 6 and 7, which were recorded most often in tests are shown in Table 3. As in 1991 and 1992, the most common pathotype was WMV2, 4, 5, 6, 7, carrying all five virulence factors. Over 80% of the isolates carried four or more of these factors, and 50% of these isolates also carried at least two of the remaining less common factors.

Table 3. Frequencies of the most commonly identified pathotypes in 1990, 1991, 1992 and 1993, as defined by WMV2, 4, 5, 6 and 7.

	Frequency of pathotype (%)			
Pathotype	1990	1991	1992	1993
2, 5, 6	9	5	3	2
2, 5, 7	5	6	9	7
2, 4, 6, 7	28	4	8	4
2, 4, 5, 6	3	5	4	1
2, 4, 5, 7	1	6	7	9
2, 5, 6, 7	6	10	10	8
2, 4, 5, 6, 7	6	55	50	63
No. of pathotypes	20	17	14	17
No. of isolates	290	317	194	356

Of the winter wheat cultivars currently on the U.K. Recommended List only two (Spark, WMRp, and Cadenza, WMR'Axona'?) have resistance factors corresponding to the less common virulence factors. Table 4 shows the proportion of the wheat mildew population tested in 1993 that is able to infect the current recommended cultivars. Over 60% of the isolates carry the virulence factors corresponding to 14 of the 16 cultivars. Cadenza and Spark are susceptible to less than 20% of the isolates. However, as these resistance factors have previously only been used in spring cultivars the selection pressure for the corresponding virulence factors has been small. It is likely that these virulence factors will become more common should Cadenza and Spark become popular. Nevertheless, these factors are the only new specific resistances to have appeared in winter wheat cultivars for several years.

Table 4. The proportion of mildew isolates tested in 1993 able to infect winter wheat cultivars on the U.K. Recommended Lists for Cereals 1994.

Cultivar	Proportion (%)	Cultivar	Proportion (%)
Beaver	93	Cadenza	10
Hussar	77	Genesis	100
Haven	93	Spark	18
Riband	68	Flame	79
Hereward	100	Admiral	92
Mercia	79	Torfrida	68
Brigadier	77	Norman	98
Hunter	93	Apollo	76

Resistance Factors in New Cultivars

The specific resistance factors identified in winter wheat cultivars are shown in Table 5.

Table 5. Specific mildew resistance factors of winter wheat cultivars.

WMR0	**WMR7**	**WMR2, 6**	**WMR6, 7**
Genesis	Beaver	Estica	Zodiac
Hereward	Haven	Buster	Lynx
Prophet	Hunter		
Rialto		**WMR2, 4, 6**	**WMR5, 'Talent'**
Andante	**WMR2, 7**	Riband	Mercia
	Admiral	Torfrida	
WMR2	Slejpner		**WMRp**
Norman		**WMR4, 7 (2, 6 ?)**	Spark
	WMR2, 4, 7	Hussar	
WMR4	Apollo	Brigadier	**WMR'Axona' ?**
Flame			Cadenza

Tests for Sensitivity to Fenpropimorph

A sample of 46 isolates collected in 1993 was tested for sensitivity to fenpropimorph. A single test with six replicates was carried out on detached leaf segments from seedlings sprayed with various rates of the fungicide. The results are summarised in Table 6, with data from similar tests carried out in 1991. Direct comparisons between the two tests cannot be made, but within each test the isolates can be compared to the control isolates, which were nearly all the same in both tests. Many of the isolates were considerably less sensitive to fenpropimorph than the sensitive controls, which were collected in the 1970s or early 1980s before fenpropimorph was widely used. Allowing for the limited number of isolates tested, the results do not indicate any change in sensitivity from 1991 to 1993.

Table 6. Sensitivity of wheat mildew to fenpropimorph.

	Growth as % of growth on untreated leaves Rate of fenpropimorph as proportion of field rate			
Sample (no. of isolates)	0.01	0.02	0.05	0.10
1993				
Headley Hall (10)	9	3	0	0
Lincs and Norfolk (12)	35	11	1	0
Bridgets and Wye (4)	6	1	0	0
Cockle Park (9)	23	4	0	0
Cambridgeshire (11)	24	0	0	0
Sensitive controls (3)	0	0	0	0
Insensitive controls (2)	36	0	0	0
1991				
Essex (10)	26	11	4	
Dundee (10)	52	48	14	-
Sensitive controls (3)	3	0	0	-
Insensitive controls (3)	93	96	11	-

CONCLUSIONS

The results of the 1993 survey were similar to those of the previous three years. A large proportion of the mildew isolates tested were able to infect the majority of the winter wheat cultivars in current commercial use, and most specific resistances do not provide effective resistance to powdery mildew. However, plant breeders are making use of partial resistance to give moderate resistance to mildew in the field.

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YELLOW RUST OF WHEAT

R A BAYLES AND P L STIGWOOD

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The frequencies of virulences WYV1, WYV2, WYV3, WYV4, WYV6, and WYV9 remained high. Virulence for Talon reached 60%. Seven new cultivars showed good adult plant resistance to all isolates, although differing from one another in seedling reactions.

INTRODUCTION

The principal aim of the wheat yellow rust survey is to detect increased virulence for specific resistances to *Puccinia striiformis* (WYR factors). In addition, specific resistances in current and new cultivars are identified. Specific resistances identified 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. Additional cultivars included in seedling tests are listed in Table 2.

Table 1. Resistance factors to *Puccinia striiformis* and differential cultivars

WYR	Gene	Type*	Differential Cultivar(s)**	WYV detected
WYR 1	Yr 1	O	Chinese 166,	1957
WYR 2	Yr 2	O	Heine VII	1955
WYR 3	Yr 3a + 4a	O	Vilmorin 23, Cappelle Desprez	1932
WYR 4	Yr 3b + 4b	O	Hybrid 46	1965
WYR 5	Yr 5	O	T. spelta album	-
WYR 6	Yr 6	O	Heines kolben	1958
WYR 7	Yr 7	O	Lee, Tommy	1971
WYR 8	Yr 8	O	Compair	1976
WYR 9	Yr 9	O	Riebesel 47/51	1974
			Kavkaz 4 X Federation	
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

* O = Overall A = Adult Plant

** Differential cultivars used in 1993 seedling tests are underlined

Table 2. Additional cultivars included in seedling differential tests

Cultivar	WYR
Carstens V	
Talon	WYR Rx (Carstens V + ?)
Hereward	WYR Rx (Carstens V + ?)
Brigadier	WYR R
Buster	WYR R
Cadenza	WYR Rx (Tonic)
Hussar	WYR R
Lynx	WYR R
Parade	WYR R
Tonic	WYR Rx
Zodiac	WYR R

Rx = specific resistance not fully identified
R = resistant to all isolates prior to 1993 survey.

METHODS

Methods used at NIAB for virulence tests have been described by Priestley, Bayles and Thomas, 1984.

1993 isolates

The incidence of yellow rust in the UK in 1993 was low and similar to that in 1992. The UKCPVS tested seventy-three isolates of *P. striiformis* using seedlings of the differential cultivars listed in Tables 1 and 2. The isolates originated from thirty-five different cultivars. Sixty-three isolates were from naturally infected plots or crops and ten from inoculated plots. Nearly all came from the eastern areas of East Anglia, the Midlands and Scotland.

1992 isolates

Sixteen isolates (Table 3) were tested on adult plants of thirty cultivars in polythene tunnels and on seedlings of a subset of twenty cultivars with unidentified resistances. Fourteen of the isolates were selected from those collected during the 1992 survey, on the basis of their seedling virulence characteristics and source cultivar. Seedling virulence for Brigadier, Parade, Tonic and Cadenza, had not been detected by the survey prior to 1992.

Table 3. Isolates of *Puccinia striiformis* used in adult plant tests.

Isolate Code	Source		WYV Factors	Additional virulence*
	Cultivar	Location		
92/13	Talon	Cambs	1,2,3,4	Ta,He,Pa
92/27	Unknown	Lincs	1,2,3,4,6,9	Hu,Br
92/39	CWW 90/5	Lincs	1,2,3,4,6,9	Hu,Br
92/48	Talon	Cambs	1,2,3,4,6	Ta,He
92/50	Spark	Cambs	1,2,3,4,6,9	Hu,Br
92/51	Atou cross	Norfolk	1,2,3	Ta,He,Pa
92/57	Wasp	Scotland	1,2,3,4,6,9	Hu,Br
92/64	Riband	Scotland	1,2,3,4,6,7	Ta,He
92/70	Soissons	Cambs	1,2,3,4,6,7,9	Ta,He,Ca,
92/506	CPB W10	Cambs	1,2,3,4,6,9	Ta,He
92/601	Hereward	Cambs	1,2,3,4,6	Ta,He
92/605	Spark	Cambs	1,2,3,4,6,9	Ta,He
92/606	Hunter	Oxon	1,2,3,4,6,9	Br
92/608	Hereward	Lincs	1,2,3,4,6,9	Ta,He
91/601	Hereward	Cambs	2,3,4,6	Ta,He
90/80	Talon	Lincs	1,2,3	Ta

* Virulence for additional cultivars at seedling stage:-

Ta = Talon, He = Hereward, Hu = Hussar, Br = Brigadier, Pa = Parade, Ca = Cadenza, To = Tonic.

RESULTS

1993 virulence frequencies from seedling tests

Seedling virulence frequencies are given in Table 4. These frequencies exclude isolates from inoculated plots. The frequencies of WYV 1, WYV 2, WYV 3, WYV 4, WYV 6 and WYV 9 remained high. There was a reduction in the frequency of WYV 6, probably due to the fact that fewer of the isolates were from cultivars with the WYR 6 resistance (eg Haven and Beaver, both WYR 6,9). The frequency of virulence for Talon increased compared with 1992 and virulence for Hereward decreased slightly. Virulence for Brigadier and Hussar remained at around 1992 levels. Four samples were received from plots of Brigadier. Although seedling virulence for Brigadier had been detected before 1993, this was the first time that samples had been received from the cultivar itself. Virulence for Lynx was detected in 16% of isolates, but no samples were received from the cultivar.

Carstens V was introduced as a differential in seedling tests. Corresponding virulence was detected in 75% of isolates, a slightly higher frequency than virulence for Talon, which possesses resistance derived from Carstens V. It is believed that, prior to 1990, when virulence for Talon was first detected, virulence for Carstens V had been at a very low level in the UK. Table 5 classifies all 73 isolates in terms of virulence for Carstens V, Talon and Hereward. There is a clear association between virulence for the three cultivars, confirming that they have a resistance in common. However, not all isolates virulent on Carstens V were virulent on Talon and Hereward, indicating that the other two cultivars possess additional resistances.

Table 4. Virulence factor frequency (%)

WYV Factor	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93
WYV 1	83	95	71	63	85	75	76	78	87	68	62	85	91	88	89
WYV 2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	98
WYV 3	100	85	95	100	100	100	100	100	100	100	100	100	100	100	100
WYV 4	17	15	29	37	20	31	45	70	47	78	97	91	86	86	89
WYV 5	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*
WYV 6	17	25	31	29	26	64	90	96	89	72	57	69	64	88	68
WYV 7	0	0	5	5	0	3	3	22	8	6	2	9	19	7	8
WYV 8	0	0	0	2	0	0	*	*	*	*	*	*	0	0	0
WYV 9	0	0	5	2	23	31	3	4	5	66	99	94	88	76	84
WYV 10	0	0	0	0	0	0	*	*	*	*	*	*	*	*	*
No. of isolates	30	20	42	41	63	36	29	23	52	71	156	67	42	77	63

Virulence for additional test cvs

Cultivar	Resistance	'91	'92	'93
Carstens V		*	*	75
Talon	WYR Rx (Carstens V + ?)	41	38	60
Hereward	WYR Rx (Carstens V + ?)	36	47	35
Brigadier	WYR R	*	40	35
Buster	WYR R	*	*	0
Cadenza	WYR Rx (R Tonic)	*	0	2
Hussar	WYR R	12	29	32
Lynx	WYR R	*	*	16
Parade	WYR R	*	3	0
Tonic	WYR Rx	*	1	2
Zodiac	WYR R	*	*	0

* differential not included in test.

Table 5. Isolates classified according to virulence for Carstens V, Talon and Hereward.

	Virulence for other cultivars				
	Ta + He	Ta	He	O	Total
Virulent on Carstens V	26	15	3	9	53
Avirulent on Carstens V	0	3	0	17	20

Ta = Talon
He = Hereward
O = neither Talon nor Hereward

1992 isolates - Adult plant and associated seedling tests

The results of adult plant tests are given in Table 6.

Seedling virulence for Parade was detected in isolate 92/13, but the isolate produced no infection on adult plants of the cultivar. The isolate with virulence for seedlings of Cadenza (92/70) failed to infect adult plants. Isolate 92/70 was also virulent on seedlings of the spring wheat cultivar Tonic, one of Cadenza's parents.

Isolates virulent on seedlings of Talon gave high levels of infection on adult plants of the cultivar, confirming that Talon has an overall specific resistance without additional adult plant resistance.

The majority of isolates with virulence for seedlings of Hereward gave low infection levels on adult plants of the cultivar. None of the 1992 isolates gave levels of infection as high as those produced by the original Hereward- virulent isolate, 91/601. It seems that the later isolates only partially match the resistance of Hereward.

Isolates with seedling virulence for Hussar and for Brigadier did not infect adult plants of these cultivars, which maintained their adult plant resistance to all isolates.

Hunter was seedling susceptible to isolates possessing WYV 6,9, indicating that it has inherited the overall resistance WYR 6,9 from its parent Haven.

Eight cultivars, denoted by asterisks in Table 6, were included in adult plant tests for the first time. Seven of these exhibited a very high degree of resistance to all isolates, although their reactions at the seedling stage differed markedly. Lynx and Zodiac were seedling resistant to all isolates, whereas Prophet was susceptible. Both Andante and Flame were susceptible to certain isolates at the seedling stage, but their specific resistances could not be identified. Buster was susceptible only to isolate 92/13 in seedling tests. This isolate was also virulent on seedlings of Parade, one of the parents of Buster, indicating that the cultivars have a specific resistance in common.

The two remaining new cultivars were less resistant than the others. Soissons, which was seedling susceptible to all isolates, appeared to have an adult plant resistance which interacted with isolate 92/13. Rialto interacted with WYV 6,9 isolates at both seedling and adult plant stages, in a manner similar to its parent Haven and clearly possesses WYR 6,9.

Amongst the established cultivars, there was an indication of increased virulence for Mercia. Isolate 92/50 gave a higher level of infection on the cultivar than recorded in previous years. Mercia's adult plant resistance has so far proved durable, despite widespread cultivation since it was added to the Recommended List in 1986.

Atou was re-introduced into tests, having last been tested in 1979. The levels of infection on Atou were higher than in earlier years, particularly with the 'Hereward' isolate 91/601. It appears that Atou's adult plant resistance is matched by the majority of isolates with virulence for Hereward or Talon.

REFERENCE

Priestley, R.H., Bayles, R.A. and Thomas, J.E. (1984). Identification of specific resistances against *Puccinia striiformis* (Yellow Rust) in winter wheat varieties. 1. Establishment of a set of type varieties for adult plant tests. *Journal of the National Institute of Agricultural Botany*, **16**, 469-476.

Table 6. **Adult Plant tests 1993. Mean per cent leaf area infection (mean of 4 assessments) - with seedling reactions where tested in 1993**

Cultivar	Isolate / WYR Factors	91/601	92/601	92/506	92/57	92/605	92/64	92/48	92/51	92/608	92/13	90/80	92/70	92/606	92/50	92/27	92/39
	WYV Factors	2,3,4,6,14	1,2,3,4,6,14	2,3,4,6,14	1,2,3,4,6,9,13,14	1,2,3,4,6,9,13,14	1,2,3,4,6,7,13,14	2,3,4,6,14	1,2,3,14	1,2,3,4,6,9,14	1,2,3	1,2,3	1,2,3,4,6,7,9	1,2,3,4,6,9,13,14	1,2,3,4,6,9,13,14	1,2,3,4,6,9,13,14	1,2,3,4,6,9,13,14
Parade	Rx+APR	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0
Rendezvous	Rx+APR	**0**	**0**	**0**	**0**	**0**	0	**0**	**0**	**0**	**0**	**0**	0	**0**	**0**	**0**	**0**
Torfrida	Rx+APR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hussar	Rx+APR	0	0	0	**0**	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Brigadier	Rx+APR	0	0	0	**0**	0	0	0	0	0	0	0	0	**0**	**0**	**0**	**0**
Cadenza	Rx(Tonic)+APR	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0
*Lynx	R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*Zodiac	R	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
*Prophet	0+APR	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
*Andante	Rx+APR	0	0	**0**	**0**	0	0	0	0	0	**0**	0	**0**	**0**	**0**	**0**	**0**
*Flame	Rx+APR	**1**	0	**0**	0	0	0	0	**1**	0	2	1	**0**	**0**	**0**	**0**	0
*Buster	Rx(Parade)+APR	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0
*Hunter	6,9+APR	0	0	0	**1**	1	0	0	0	0	0	0	0	**1**	**1**	**0**	**1**
Mercia	3+APR	1	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
*Soissons	Rx+APR	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**4**	**0**	**1**	**0**	**0**	**0**	**1**
Talon	Carstens V+	**22**	**14**	**14**	**16**	**14**	**13**	**12**	**16**	**13**	**15**	**24**	**15**	**13**	**11**	1	0
Hereward	Carstens V+	**7**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**1**	0	0	0	0	0	0	0
Spark	Carstens V+	**4**	**1**	**0**	**1**	**2**	**1**	**1**	**1**	1	0	**0**	**0**	**0**	**2**	**0**	**1**
Atou	Carstens V+	**6**	**2**	**3**	**1**	**2**	**3**	**2**	**3**	**1**	**1**	**3**	**0**	0	**0**	**0**	**0**
M Huntsman	2,13	0	0	0	5	4	3	0	2	0	0	3	2	6	9	3	4
Hustler	1,2,13	1	1	4	12	5	12	4	1	6	2	1	4	11	12	14	6
Riband	13	0	0	1	7	5	12	1	2	2	1	2	4	6	8	10	9
Hobbit	14	15	11	11	12	14	6	11	8	9	1	1	6?	15	14	17	15
Apollo	9	0	0	0	2	3	0	0	0	2	0	0	1	1	4	6	5
Admiral	9	0	1	1	6	0	0	5	0	2	0	0	3	5	9	10	10
Haven	6,9	2	0	6	15	14	9	5	1	8	5	7	12	16	15	18	16
Beaver	6,9	1	1	4	13	11	7	7	0	5	0	1	8	12	12	14	13
*Rialto	6,9	1	0	3	**11**	**10**	6	5	1	6	2	9	**8**	**14**	**13**	**10**	**14**
Brock	7,14	0	0	0	0	0	0	0	2	1	0	1	5	4	0	0	0
Genesis	0	**2**	**1**	**0**	**1**	**1**	**2**	**1**	**5**	**1**	**2**	**2**	**2**	**0**	**3**	**2**	**0**

* = new varieties; first year in adult plant tests.
varieties shown in italics not seedling tested in 1993

Boxes highlight variety x isolate interactions; they have no statistical significance.
Values **underlined, bold** indicate susceptible in 1993 seedling tests

BROWN RUST OF WHEAT

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Seedling tests with the 1993 isolates of brown rust identified virulence combinations not detected in recent years. Adult plant tests in field isolation nurseries inoculated with specific isolates of *P. recondita* enabled the spring and winter wheat cultivars to be grouped on the basis of similarities in their patterns of response. Seedling and adult plant tests carried out in controlled environments identified several winter wheat cultivars as carrying resistance effective only at the adult plant stage of growth. Some of these resistances were temperature-sensitive in controlled climate tests. Virulence to Hunter, Hussar and Brigadier was detected for the first time and, in one isolate from Kent, this was combined with virulence for Hereward and Spark.

GLASSHOUSE SEEDLING TESTS WITH 1993 ISOLATES

High levels of wheat brown rust in 1993, combined with concern at the identification of some new pathotypes in 1992, was reflected in a large number (86) of samples received. This number included 32 from the CSL-ADAS Cereal Disease Survey, courtesy of Dr R Polley and colleagues. The samples were from 23 winter wheat cultivars and included infected leaf samples from cvs Hunter (2), Brigadier (2), Estica (2), Hussar (2) and Hereward (6). These cultivars were resistant to isolates of *Puccinia recondita* introduced into field nurseries at IGER, Aberystwyth, and NIAB, Cambridge, in 1992, although one isolate, WBRS-90-9, induced low levels of disease on cvs Hussar and Hereward at the latter site. The severity of brown rust infection on the crops from which the majority of these samples were obtained is unknown. A demonstration plot of cv. Hussar grown at the NIAB, Cambridge, from which a sample was received, displayed infection levels of up to 25% on the flag leaf whilst another, taken at the same location from a plot of cv. Hereward, had 10% of the flag leaf infected in foci. The geographic origins of the samples are given in Table 1.

Isolates were obtained from 53 of the samples and tested on differential cultivars which comprised the standard WBR cultivars, cv. Thatcher backcross lines carrying different Lr resistance factors, and 20 other spring and winter wheat cultivars from the NIAB Recommended List and Recommended List Trials (Table 2).

Plants were grown and inoculated under standard conditions and, following incubation in dew-simulation chambers, were transferred to either of two 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. Geographical origin of 1993 wheat brown rust samples

Location		Number of samples
England (ADAS region)		
	East	54
	South	16
	West-central	4
	South-west	4
	East-central	3
	North	1
Wales		3
Unknown		1

Table 2. Differential cultivars

Standard differential cultivars		Thatcher Lr lines	Spring* and winter cultivars	
Clement	(WBR-1)	Lr 1	Alexandria*	Zodiac
Maris Fundin	(WBR-2)	Lr 2a	Rascal*	Slejpner
Norman	(WBR-2)	Lr 3	Promessa*	Hussar
Hobbit	(WBR-2)	Lr 3bg	Baldus*	Hunter
Sappo	(WBR-3)	Lr 3ka	Sampan*	Spark
Maris Halberd	(WBR-4)	Lr 9	Axona*	Brigadier
Gamin	(WBR-6)	Lr 15	Avans*	Turpin
Sterna	(WBR-7)	Lr 19	Rialto	CWW 91/1
Sabre	(WBR-7)	Lr 24	Lynx	CWW 91/3
Armada	(WBR-0)		Dynamo	CWW 91/5

Results

Isolate/cultivar interactions were classified on the standard 0-4 scale as resistant (R: 0-2) or susceptible (S: 3-4). 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. The virulence combinations detected and their frequencies compared with the previous six years are given in Table 3. The frequencies of individual virulences over the same period are given in Table 4.

Table 3. Virulence combinations and their frequencies identified from the 1993 isolates compared with the previous six years

WBV formula	Frequency						
	1987	1988	1989	1990	1991	1992	1993
6	0.20	0.04	0	0.02	0	0.06	0.04
1,6	0.03	0	0	0	0	0	0
2,6	0.61	0.96*	0.33	0.27	0.06	0.12	0.09*
1,2,6	0.08	0	0.67	0.67	0.82	0.76	0.75*
1,3,6	0	0	0	0	0	0	0.02
2,6,7	0	0	0	0.04•	0	0	0
1,2,3,6	0	0	0	0	0	0	0.06
1,2,4,6	0	0	0	0	0.06	0	0
1,2,6,7	0	0	0	0	0	0	0.04■
1,2,3,4,6	0.08	0	0	0	0.06	0.06	0
Number of isolates tested	36	26	12	51	18	17	53

* some isolates did not carry virulence to all three WBR-2 differential cultivars

■ 1 isolate only carried virulence to cv. Sterna and to cv. Sabre

• isolates not virulent on cv. Sabre at high temperature (25°C)

Table 4. Virulence frequencies corresponding to each differential cultivar (UK CPV Surveys 1987-1993)

Cultivar	WBR factor	Frequency						
		1987	1988	1989	1990	1991	1992	1993
Clement	1	0.11	0	0.67	0.66	0.94	0.82	0.87
Fundin	2*	0.78	0.96	1.00	0.98	1.00	0.94	0.83
Norman	2*	0.78	0.85	1.00	0.98	1.00	0.94	0.94
Hobbit	2*	0.78	0.88	1.00	0.98	1.00	0.94	0.94
Sappo	3*	0.08	0	0	0	0.06	0.06	0.08
Halberd	4*	0.08	0	0	0	0.11	0.06	0
Gamin	6	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sterna	7*	0	0	0	0.04	0	0	0.04
Sabre	7*	0	0	0	0	0	0	0.02
Armada	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Number of isolates		36	26	12	51	18	17	53

*Temperature sensitive

Three virulence combinations which had not been detected in recent years were identified from the 1993 isolates. Two isolates combined virulence factors 2,6,7 (identified from 2 brown rust samples in 1990), with virulence to cv. Clement (WBR-1). One of these isolates, WBRS-93-79, overcame the temperature-sensitive resistance of cvs Sterna (WBR-7) and Sabre (WBR-7). The other was compatible only with cv. Sterna at both temperature regimes, inducing a mixed response of a mainly resistant type on cv. Sabre at 25°C.

The two other previously unidentified virulence factor combinations, 1,3,6 and 1,2,3,6, were detected in 1 and 3 isolates respectively. Virulence to cv. Sappo (WBR-3), which remains at a low frequency in the pathogen population, was common to these four isolates, which failed to overcome the low temperature resistance of cv. Halberd (WBR-4). Pathotypes that differentiate the WBR-3 and WBR-4 resistances rarely occur.

The high temperature resistance WBR-2, present in cvs Maris Fundin, Norman and Hobbit, was ineffective against all the isolates at the low temperature regime. Virulence was common with resistance being effective to only 3 isolates at 25°C, a mixed reaction of a mainly resistant type being displayed. An additional 6 isolates were avirulent on cv. Fundin at the higher temperature. These cultivars have previously been separated on their reactions to certain isolates (Clifford *et al.*, 1982), cvs Norman and Hobbit reacting more alike. Only 1 isolate, WBRS-93-79, was compatible with cvs Sterna (WBR-7) and Sabre (WBR-7) at 10°C and 25°C. Cultivar Sterna was also susceptible to isolate WBRS-93-50 at both temperature regimes, but the resistance of cv. Sabre was effective against this isolate at 25°C. The remaining isolates failed to overcome the temperature-sensitive resistance of these cultivars at the higher temperature, but at 10°C a number of isolates induced a susceptible reaction, of a mainly mixed type, on both cultivars.

The reactions of the Thatcher-Lr backcross lines, which are known to carry specific Lr genes, to the 1993 isolates are given in Table 5.

Table 5 Reaction of Thatcher-Lr backcross lines to 1993 isolates of *P. recondita* at two temperatures, 10°C and 25°C

Reaction Profile		Thatcher Line (Lr gene)								
10°C	25°C	Lr1	Lr2a	Lr3	Lr3bg	Lr3ka	Lr9	Lr15	Lr19	Lr24
R,MR	R,MR	20*	3	37	22	39	28	17	43	44
R,MR	MS,S	2	4	1	1			16		
MS,S	R,MR	13	32	13	14	12	16	4		2
MS,S	MS,S	2	11	2	4	1		16		

R = resistant; MR = mixed resistant
S = susceptible; MS = mixed susceptible
* Number of isolates

All Lr genes proved to be temperature-sensitive except Lr19 where resistance to all isolates tested was expressed at both high and low temperatures.

The only other resistances effective against all isolates were those of Lr9 and Lr24. With these, as had been observed previously (Nazim and Clifford, 1983), high temperature resistance was expressed only against some isolates whereas, with the majority, the resistances operated at both temperatures.

With Lr1, Lr2a and the Lr3 group, where temperature sensitivity was expressed, resistance was generally observed at the higher temperature. This was not the case with Lr15, where low temperature resistance occurred. In the latter, 16 isolates were virulent at both temperatures, 17 avirulent at both and 16 virulent at the high temperature. Thus, this resistance would be classified as a low temperature factor except for the anomalous result with 4 isolates, where the reverse was observed; similar anomalies occurred with Lr1, Lr2a, Lr3 and Lr3bg. The only other low temperature resistances have been identified in the spring cvs Sappo and Halberd and in the Thatcher Lr15 line. However, different patterns of responses to isolates between these genotypes indicate that the resistances are not the same. The patterns of responses within the Lr3 group were similar for each line confirming their genetic relationships.

The Lr gene lines tested here are those selected earlier as being most resistant and thus of most use in U.K. breeding programmes. However, virulence to all except Lr19 has been previously detected and confirmed in 1993. Lr19 remains effective against all isolates tested to date. This, together with cvs Sterna and Sabre (WBR-7) and the spring cvs Sappo and Halberd, which have been tested against a large number of isolates over a long period of time, would appear to offer the best sources of overall resistance for breeders.

The spring wheat cvs Alexandria, Sampan and Axona and the winter wheats Spark, Dynamo and CWW91/3 were susceptible to all isolates. Cultivars Zodiac, Slejpner, Hunter and CWW91/1 gave a pattern of response similar to cv. Clement (WBR-1) indicating a common resistance. Cultivars Turpin and CWW91/5 were susceptible to isolates carrying virulence factor WBV-1 but appear to have a temperature-sensitive resistance effective against some WBV-1 isolates at the high temperature regime. Cultivars Hussar, Brigadier and Lynx displayed mixed responses with resistance being expressed at a higher frequency at 25°C. The spring wheats Avans, Rascal and Baldus carry low temperature resistances which were effective against 41, 25 and 29 of the isolates respectively, suggesting that they differ from each other. Cultivar Rialto was susceptible to 24 isolates and resistant to 10, with the remainder inducing a mixed response at both temperatures. Three isolates only were compatible with the resistance carried by cv. Promessa spring wheat with an additional 2 isolates inducing a susceptible response at 25°C.

ADULT PLANT TESTS IN FIELD ISOLATION NURSERIES

Thirty-one winter and 11 spring wheat cultivars were sown in each of three nurseries in the 1992-1993 season using standard procedures. The nurseries were isolated from each other by a distance of at least 500 m and were inoculated with either one of the following isolates of *P. recondita*.

Isolate	Origin
WBRS-90-9 (WBV-1,2)	cv. Avalon, Spalding, Lincs.
WBRS-91-65 (WBV-1,2,3,4)	cv. Pastiche, Grantchester, Cambs
WBRS-91-67 (WBV-1,2)	cv. Virtue, Cambridge

The virulence factors carried by the 3 isolates were identified from seedling tests and it may be that the isolates carry additional virulence(s) which can only be identified by host plant reactions at the adult stage of growth.

Results

These are summarised in Table 6. High levels of disease built up on the spreader cultivars within the nurseries, with higher levels of brown rust being recorded on the susceptible cultivars growing within the nursery inoculated with isolate WBRS-91-65. Using data from the nurseries, together with results from seedling tests and from the previous year's adult plant tests, the wheat cultivars were classified into groups. It should not be interpreted that cultivars within a particular group carry a common resistance factor(s) *a priori*.

Groups 1, 1a, 1b: Within these groups cvs Slejpner, Beaver, Haven, Apollo and Admiral have been identified, with the occasional exception, as responding in a way similar to cv. Clement (WBR-1) in seedling tests to the isolates in the year(s) in which each was tested.

Adult plant tests in field nurseries, inoculated with defined isolates of the pathogen, have in recent years indicated that some cultivars identified in seedling tests as carrying WBR-1 express resistance at the adult plant stage of growth to isolates carrying the corresponding virulence factor WBV-1 (Jones and Clifford, 1988).

Cultivar Clement was susceptible within the three nurseries to the introduced isolates, although disease levels on this cultivar were lower within the nursery inoculated with isolate WBRS-90-9. None of the other cultivars identified from seedling tests as carrying resistance factor WBR-1 displayed a similar pattern of response to cv. Clement to the 3 isolates, indicating the presence of additional and differentiating adult plant resistances.

Cultivar Slejpner has previously expressed high levels of resistance as an adult plant to WBV-1 pathotypes to which it was susceptible as a seedling. The resistance of this cultivar was effective to 2 of the isolates with only WBRS-90-9 inducing a susceptible response. This isolate has previously been shown (Jones and Clifford, 1992) to carry virulence compatible with the resistance carried by cv. Slejpner. The resistance of cvs Beaver and Haven to isolate WBRS-91-65 in seedling tests and to the same isolate in adult plant tests under controlled environmental conditions in 1992 was confirmed in the 1993 isolation nurseries. It had previously been thought that these 2 cultivars carried adult plant resistance in common with cv. Slejpner but it may be that they carry WBR-1 plus additional overall resistance effective against some WBV-1 pathotypes. Also placed within Group 1a, on the basis of similarities in their patterns of response to the isolates, are the spring wheats Tonic and Alexandria, although there is no evidence from seedling tests that either carry resistance factor WBR-1.

Within Group 1b, cvs Apollo and Admiral expressed resistance to isolate WBRS-90-9, confirming the low levels of disease recorded on them to the same isolate in spreader bed tests at the NIAB, Cambridge, during 1992 (Mitchell, 1993). These cultivars appear to carry resistance additional to WBR-1 effective only at the adult plant stage of growth but different to that displayed by cv. Slejpner. The winter wheat cvs Pastiche and Soissons are also placed within this group because of similarities in their responses to the 3 isolates. They are seedling-susceptible to all isolates tested but have adult plant resistance ineffective only to isolate WBRS-91-65, which was cultured from an infected leaf sample of cv. Pastiche.

Group 2: Cultivars Fundin, Norman and Hobbit (WBR-2) displayed quantitative differences in susceptibility to the 3 isolates, all of which were identified in seedling tests as carrying the corresponding virulence factor WBV-2. Cultivars Hobbit and Norman, which carry additional resistance to Fundin (Clifford *et al.*, 1982), were more resistant within each nursery.

Group 3: Cultivar Sappo (WBR-3) was susceptible to isolates WBRS-90-9 and WBRS-91-67 both of which infected this cultivar at the high temperature regime only in seedling tests. It expressed a low level of infection within the nursery inoculated with isolate WBRS-91-65, which was previously identified in seedling tests as carrying the corresponding virulence factor. Seedling tests with previous years' isolates indicate that the spring wheat cvs Canon and Baldus carry WBR-3, but also have additional adult plant resistance. Isolate WBRS-91-67 induced a susceptible response on cv. Canon within the 1993 field nursery but the resistance of cv. Baldus remained effective, indicating that it carries additional or different resistance. The situation regarding Group 3 cultivars is complex and requires further study.

Other Groups: Cultivar Gamin (WBR-6) expressed low levels of infection to the isolates although it had been susceptible in seedling tests. This pattern of response has been observed previously (Jones and Clifford, 1989). Cultivar Gamin appears to carry adult plant resistance effective against some pathotypes. Isolate WBRS-91-65 failed to overcome the specific resistance of cv. Avalon (WBR-9), although it was susceptible to the same isolate in spreader bed tests at the NIAB, Cambridge, in 1992.

Cultivar Buster has been grouped with cv. Ranger (WBR-8) on the basis of similarities in its pattern of response to the 3 isolates.

A number of cultivars have unclassified resistances. Of these, cvs Galahad and Mercia responded similarly (Group 11) and this confirms previous observations that they carry a common specific resistance. In these tests they were susceptible to isolate WBRS-91-65, although cv. Mercia was resistant to the same isolate in 1992 NIAB spreader bed tests (Mitchell, 1993).

The above groupings enable cultivars to be classified into Diversification Groups for use by farmers and advisers.

Table 6. Reactions of winter and spring* wheat cultivars to specific isolates of *Puccinia recondita* in field isolation nurseries in 1993

Cultivar (NIAB rating)		Group	WBR factor	WBRS-90-9 (WBV-1,2)	WBRS-91-65 (WBV-1,2,3,4)	WBRS-91-67 (WBV-1,2)
Clement		1	1	9	26	22
Slejpner		1a	1+APR	10 MS	Trace	0.1
Beaver	(4)		1+OR	9	0.5	4
Haven	(3)		1+OR	12	1	9
Tonic*	(3)			16	Trace	3
Alexandria*	(3)			5 MS	0	0
Apollo	(5)	1b	1+APR	0.5 MS	22	3
Admiral	(5)		1+APR	0.5 MS	6	1 MS
Soissons				Trace	31	4
Pastiche				0	14	0.5
Fundin		2	2	3	10	5
Norman	(7)		2	0.1 MS	2	0.5
Hobbit			2	0.5 MS	3	2
Sappo*		3	3	11	1	19
Canon*	(6)			1	1	7
Baldus*	(7)			0	Trace	0
Halberd*		4	4	0.5 MS	0	0.5 MS
Huntsman		5	5	6	19	13
Gamin		6	6+APR	3	Trace	2
Sterna		7	7	0.1	0	Trace
Sabre			7	0	0	0
Ranger		8	8	Trace	Trace	10
Kinsman				Trace	Trace	1 MS
Buster				Trace	0.1	7
Avalon		9	9	11	Trace	16
Talon		10		22	33	26
Armada				8	27	12
Galahad		11		1	16	5
Mercia	(6)			1	13	3
Riband	(4)			2 MS	5	7
Rialto		12		3	1	3
Rascal*				1 MS	0	0
Hereward	(8)			0	0	Trace
Hussar	(6)			0	0	0
Andante				0	0	0
Lynx				0	0	0
Prophet				0	0	0
Flame	(9)			0	0	0
Axona*	(9)			0	0	0
Avans*	(3)			0	0	0
Promessa*	(9)			0	0	0
Sampan*				0	0	0

Mean of 3 replicates, 2 assessment dates
All reaction types susceptible unless stated
MS = mixed susceptible; APR = adult plant resistance;
OR = overall resistance;
( ) NIAB rating; 1 = susceptible; 9 = resistant

CONTROLLED ENVIRONMENT TESTS

1. Tests with Standard Isolates

The appearance in the field of new races of wheat brown rust capable of overcoming the resistances of recently introduced wheat cultivars is of concern. The resistances carried by these varieties need to be identified for their deployment in varietal diversification schemes. Classifying these resistances is complicated because some cultivars only express their resistance during later growth stages (adult plant resistance - APR). Additionally, some of these resistances may be temperature-sensitive (TS), being effective at either high or low temperatures. The objective of the following tests was to characterise the resistances carried by some of these newly introduced cultivars, several of which have displayed high levels of resistance to UK pathotypes.

Materials and Methods

Fourteen winter wheat cultivars were grown in a spore-proofed glasshouse to the flowering stage of growth. The same cultivars, plus an additional 22 winter and spring wheats, were grown under the same conditions until the second leaf was fully emerged. The cultivars were inoculated with one of each of the following isolates:

Isolate	Origin
WBRS-86-9 (WBV-2,3,4)	cv. CWW 4217/15, Cambridge
WBRS-90-9 (WBV-1,2)	cv. Avalon, Spalding, Lincs
WBRS-91-65 (WBV-2,3,4)	cv. Pastiche, Grantchester, Cambs
WBRS-87-9 (WBV-1,2)	cv. Avalon, Canterbury, Kent
WBRS-91-66 (WBV-1,2)	cv. Virtue, Cambridge
WBRS-91-67 (WBV-1,2)	cv. Virtue, Cambridge

The virulence factors given for the isolates were identified from seedling tests, although adult plant tests in field isolation nurseries have shown that these isolates carry virulence factors in different combinations to those identified in seedling tests (UKCPVS Annual Reports, 1987-1993). This is because some of the differential cultivars carry resistance which can only be identified at the adult plant stages of growth. In addition, the field nurseries may also become contaminated with naturally occurring inoculum of other brown rust pathotypes, confounding the expected cultivar x isolate interactions.

The isolates used here were selected on the basis of the responses of the differential and additional cultivars to them in seedling and/or adult plant tests. Also, some of the isolates had shown virulence to previously resistant cultivars in 1992 spreader bed tests at the NIAB, Cambridge (Mitchell, 1993). Seedlings (4 replicates) and adult plants (2 replicates) of each cultivar were incubated under each of the following regimes following plant culture in a sporeproof glasshouse and inoculation under standard conditions.

1. 10°C constant and 12 h photoperiod
2. 25°C, 16 h photoperiod: 10°C, 8 h dark
3. 25°C constant and 16 h photoperiod

Results

Results of the seedling tests are summarised in Table 7 and of the adult plant tests in Table 8.

Isolate/cultivar interactions were classified on the standard 0-4 scale as resistant (R: 0-2) or susceptible (S: 3-4). Where a mixture of responses was observed on the same leaf, the cultivar was classified as resistant or susceptible on the basis of the predominant reaction type, i.e. MR (mixed resistant) denotes a mainly resistant response with some type 3-4 pustules. Within the adult plant tests, cultivars were classified as resistant (R) or susceptible (S) on the responses of the 2 replicates. Where differences occurred between replicates, both reactions are given. Assessments of reaction type were made 9 days post-inoculation at 25°C, 11 days post-inoculation at 25°/10°C and 26 days post-inoculation at 10°C constant temperature. The adult plants and seedlings were assessed on the responses of the last-formed (flag) leaf and first (seedling) leaf respectively.

SEEDLING TESTS

There was no indication of temperature affecting the host:pathogen relationship in these tests, but there were specific cultivar x isolate interactions which allowed classification of the cultivars into groups based on similarities of response.

Cultivars Buster, Avalon, Pastiche, Soissons, Virtue, Hereward and Spark which have previously been observed as carrying APR were susceptible to all of the isolates at all temperatures. Cultivar Armada (susceptible check) was also susceptible.

Seedlings of cvs Slejpner and Zodiac have, in previous tests, expressed patterns of response similar to each other and to cv. Clement (WBR-1) to the isolates against which they have been tested. Cultivar Hunter has also been identified as carrying WBR-1 from these seedling tests although it appears to carry additional resistance which is effective against some WBV-1 isolates but not others. In the present tests, cvs Clement, Slejpner and Zodiac were susceptible to 4 of the isolates at all temperatures. This included isolate WBRS-86-9 which was not thought to carry WBV-1 but these results clearly indicate that it does. These cultivars gave a mixed response to the other 2 isolates, WBRS-91-65 and WBRS-91-66. The former gave a mainly resistant reaction at 25°C although it was virulent on cv. Clement in the 1991 seedling tests at this temperature. Cultivar Hunter which carries WBR-1 was, however, less susceptible than cvs Clement, Zodiac and Slejpner, particularly at the lower temperatures with isolate WBRS-91-65, to which it had also been resistant when tested in 1991. This isolate also lacked virulence to cvs Haven and Beaver (WBR1+) in 1991 seedling tests. These results generally confirm the relationships between these four cultivars.

Cultivars Hussar and Brigadier were resistant to all isolates including WBRS-90-9 to which cv. Hussar was susceptible in spreader bed tests at the NIAB, Cambridge, in 1992.

ADULT PLANT TESTS

Previous field tests have identified cv. Buster as carrying a race-specific, adult plant resistance. Of the 3 isolates to which this cultivar has been exposed in the field, and which were tested here (Table 8), only isolate WBRS-91-67 was virulent. To isolates WBRS-91-65 and WBRS-86-9 it was susceptible at 25°/10°C and 25°C constant but resistant at 10°C. In the field in 1993, it was resistant to WBRS-90-9 although in the tests reported here, there were replicate differences presumably due to a mixed seed lot. From the reactions overall, it may be deduced that cv. Buster would express resistance in the field to isolates WBRS-86-9 and WBRS-91-66 under cool temperature conditions, and that it would be susceptible to isolate WBRS-87-9 which overcomes the resistance at all three temperatures.

The only other APR which is expressed at 10°C only was observed in cv. Avalon (WBR-9) when tested to 5 of the 6 isolates. To the other isolate, WBRS-87-9, resistance was expressed at all three temperatures: it had also been resistant to this isolate in 1988 field nurseries. Isolates WBRS-91-66 and WBRS-91-65 had failed to infect cv. Avalon in field nurseries in 1992 and 1993 respectively, although spreader bed tests at the NIAB, Cambridge, in 1992 had shown it to be susceptible to WBRS-91-65. In the tests reported here, these 2 isolates were virulent at the higher temperature regimes. Cultivar Avalon was also resistant at 10°C to the other 3 isolates tested but in the field was susceptible to them in the seasons in which they were tested. It differs from cv. Buster in that it expresses resistance at 10°C to isolates identified in the field as carrying WBV-8, confirming previous classification.

The 1993 field nursery tests reported above suggest that cvs Pastiche and Soissons carry in common a race-specific APR which was overcome by isolate WBRS-91-65. Data for cv. Soissons in the controlled environment tests are incomplete rendering comparisons in its reactions to the isolates with cv. Pastiche difficult. Cultivar Pastiche was susceptible to isolate WBRS-91-65 at 25°/10°C and 25°C but was resistant at 10°C. These tests indicate that the resistance of cv. Pastiche may be ineffective at 25°C against some isolates of the pathogen to which it is resistant in the field, but is effective at low temperatures to an isolate which does carry virulence to it in field tests.

The responses of cv. Clement (WBR-1) to some isolates in these tests did not confirm field nursery results. It had been resistant to isolate WBRS-86-9 in the 1987 field nurseries (and in 1986 seedling tests) but was susceptible in the present adult plant controlled environment tests, indicating contamination of this nursery with WBV-1 pathotypes. Conversely, isolates WBRS-91-65 and WBRS-91-66 were avirulent in adult plant tests reported here but were virulent in the field nurseries in 1993 and 1992 respectively. These 2 isolates induced a mixed, mainly susceptible response on cv. Clement in the controlled environment seedling tests but were virulent on it at 10°C and 25°C in similar tests conducted in 1991.

Data from previous years' seedling and field tests have suggested that cvs Zodiac and Hunter carry resistance factor WBR-1 plus additional APR similar to cv. Slejpner. Isolate WBRS-90-9 was virulent on cv. Slejpner in the 1993 field nursery at Aberystwyth and on cv. Zodiac in spreader bed tests at the NIAB in 1992, but failed to infect cv. Hunter in the same tests, confirming previous seedling test results that the latter carries additional resistance. The resistance(s) expressed by these 3 cultivars was effective against all the isolates in these controlled environment tests, including WBRS-90-9, although the latter was virulent on one replicate of cv. Slejpner at 25°C. It is difficult to explain why the resistance of cvs Slejpner and Zodiac remained effective to isolate WBRS-90-9 in these tests. The host/pathogen interactions appear to be unaffected by temperature.

The APR of cv. Spark was overcome only by isolate WBRS-91-66 and this at the higher temperature regimes. This cultivar had displayed low levels of susceptibility (0.5%) to the same isolate in the 1992 isolation nurseries. These results suggest that cv. Spark has a specific resistance which is overcome at high temperatures only by certain isolates. The susceptible response of this cultivar to isolates WBRS-90-9 and WBRS-91-67 in spreader bed tests at the NIAB, Cambridge, in 1992 was not confirmed, but this may be explained by the different test environments.

Virulence carried by isolate WBRS-90-9 to cv. Hussar, identified in spreader bed tests at the NIAB, Cambridge, in 1992 and in tests under controlled environmental conditions at Aberystwyth in the same year, was not confirmed. This cultivar appears to carry a resistance of the overall type as does cv. Brigadier, which remained effective in these tests.

The adult plant resistance(s) of cvs Virtue and Hereward were effective to the isolates against which they were tested, although cv. Hereward was susceptible at the simulated day/night regime to isolate WBRS-91-65. A mechanistic explanation for this anomaly does not present itself readily.

2. Tests with 1993 Survey Isolates

Additional tests with isolates cultured from infected leaves sampled during 1993 from previously highly resistant cultivars were conducted on adult plants at two constant temperatures, 10°C and 25°C. The results are presented in Table 9. One isolate, WBRS-93-80, was virulent on cvs Slejpner, Zodiac and Hunter at 10°C and 25°C confirming their common resistance. It was also virulent on cvs Brigadier and Hussar, but at the higher temperatures only in the case of the latter. Another, WBRS-93-87, failed to infect these cultivars but was virulent on cvs Hereward and Spark, reflecting the relatedness of their resistances. Isolates such as these, which differentiate cultivar resistances, are valuable for classifying the cultivars for deployment into diversification groups.

Isolate WBRS-93-56, sampled from a crop of cv. Hunter, grown in Kent, is a cause for concern as it combines the virulences of the above 2 isolates. Pathotypes carrying such a wide range of virulences will, if they become widespread, pose a major threat to wheat crops and will reduce the opportunities for, and the value of, cultivar diversification.

The resistance of the spring wheat cv. Rascal, which was identified as temperature-sensitive and effective at 10°C against a number of isolates in the 1993 seedling tests, was effective at 10°C to all the isolates in these tests. The low temperature resistance of cvs Pastiche and Soissons was also effective against all 6 isolates but 4 overcame the temperature-sensitive resistance of cv. Avalon identified previously.

Summary

The host/pathogen interactions observed in the controlled environment tests reported here have enabled the types of resistance carried by the cultivars to be classified with some degree of certainty but further tests are required to confirm. These are summarised in Table 10.

Virulence to cvs Pastiche and Soissons has been identified in the field but not at 10°C to the specific isolates used in these tests. Cultivar Virtue, classified with cvs Hereward and Spark, was not included in the additional tests with the 1993 isolates. Data from these controlled environment tests should therefore be used in conjunction with those from other tests when grouping the cultivars on similarities in their resistance(s) for the assembly of diversification schemes.

Table 10 Cultivar resistance types identified in controlled environment tests

Cultivar (WBR-factor)	Resistance type	TS	Virulence detected
Buster (8?)	APR	Yes (Low)	Yes
Avalon (9)	APR	Yes (Low)	Yes
Pastiche, Soissons (?)	APR	Yes (Low)	Yes?
Slejpner, Zodiac (1)	APR	No	Yes
Hunter (1+)	APR + OR	No	Yes
Hussar, Brigadier	OR	No	Yes
Spark	APR	Yes (Low)	Yes
Hereward	APR	No	Yes
Virtue	APR	No	No

APR = Adult Plant Resistance
OR = Overall Resistance
TS = Temperature Sensitive

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Table 7. Reactions of winter wheat cultivars (seedlings) to specific isolates of *P. recondita* under controlled environmental conditions

Cultivar		Buster	Avalon	Pastiche	Soissons	Clement	Slejpner	Zodiac	Hunter	Virtue	Hereward	Spark	Hussar	Brigadier	Armada
Isolate	Incubation Temp. °C														
WBRS-86-9	10	S	S	S	S	S	S	MS	MS	S	S	S	R	R	S
	25/10	S	S	S	S	S	MS	S	MR	S	S	S	R	MR	S
	25	S	S	S	S	S	S	S	S	S	S	S	MR	MR	S
WBRS-91-67	10	S	S	S	S	S	S	S	MS	S	S	S	MR	MR	S
	25/10	S	S	S	S	S	S	MS	MS	S	S	S	R	R	S
	25	S	S	S	S	S	S	S	S	S	S	S	R	MR	S
WBRS-90-9	10	S	S	S	S	S	S	S	S	S	S	S	R	MR	S
	25/10	S	S	S	S	S	S	S	S	S	S	S	MR	MR	S
	25	S	S	S	S	S	S	S	S	S	S	S	MR	MR	S
WBRS-87-9	10	S	S	S	S	S	S	S	MS	S	S	S	R	MR	S
	25/10	S	S	S	S	S	S	S	MR	S	S	S	R	R	S
	25	S	S	S	S	S	S	S	MS	S	S	S	R	R	S
WBRS-91-65	10	S	S	S	S	MS	MS	MS	R	S	S	S	R	R	S
	25/10	S	S	S	S	MS	MS	MS	MR	S	S	S	R	R	S
	25	S	S	S	S	MR	MR	MR	R	S	S	S	R	R	S
WBRS-91-66	10	S	S	S	S	MR	MS	MR	MS	S	S	S	R	MR	S
	25/10	S	S	S	S	MS	MS	MS	MS	S	S	S	MR	MR	S
	25	S	S	S	S	MS	MS	MS	MS	S	S	S	MR	MR	S

Reaction type assessed on 2 replicates.
S = susceptible R = resistant
MR = Mixed resistant MS = Mixed susceptible

Table 8. Reactions of winter wheat cultivars (adult plants) to specific isolates of *P. recondita* under controlled environmental conditions

Cultivar / Isolate	Incubation Temp. °C	Buster	Avalon	Pastiche	Soissons	Clement	Slejpner	Zodiac	Hunter	Virtue	Hereward	Spark	Hussar	Brigadier	Armada
WBRS-86-9	10	R	R	R	R	S	R	R	R	R		R	R	R	S
	25/10	S	S	R	R	S	R	R	R	R		R	R	R	S
	25	S	S	R/S	R	S	R	R	R	R		R	R	R	S
WBRS-91-67	10	S	R	R		S	R	R	R		R	R	R	R	S
	25/10	S	S	R		S	R	R	R		R	R	R	R	S
	25	S	S	S/R		S	R	R	R		R	R	R	R	S
WBRS-90-9	10	S/R	R	R	R	S/R	R	R	R	R		R	R	R	S
	25/10	R	R/S	R	R	R	R	R	R	R		R	R	R	S
	25	S/R	S	S	R	S	R/S	R	R	R		R/S	R	R	S
WBRS-87-9	10	S	R	R	R	S	R	R	R	R	R	R	R	R	S
	25/10	S	R	R	R	S	R	R	R	R	R	R	R	R	S
	25	S	R	R	R	S/R	R	R	R	R	R	R	R	R	S
WBRS-91-65	10	R	R	R		R	R	R	R	R	R	R	R	R	S
	25/10	S	S	S		R	R	R	R	R	S	R	R	R	S
	25	S	S/R	S	S	R	R	R	R	R	R	R	R	R	S
WBRS-91-66	10	R	R	R	S	R	R	R	R		R	R	R	R	S
	25/10	S	S	R		R	R	R	R		R	S	R	R	S
	25	S	S	S/R		R	R	R	R		R	S	R	R	S

Reaction type assessed on 2 replicates. Both responses given where replicates differ (-/-).
S = susceptible R = resistant

Table 9. Reactions of wheat cultivars (adult plants) to specific isolates of *P. recondita* at 10°C and 25°C

Cultivar			Buster	Avalon	Pastiche	Soissons	Slejpner	Zodiac	Hunter	Hereward	Spark	Hussar	Brigadier	Rascal
Isolate	Origin	Incubation Temp. °C												
WBRS-91-65	Pastiche Cambs	10 25	R S	MR S	R S	MR S	R R	R R	R R	R R	R MR	R R	R R	R S
WBRS-93-75	Hunter Lincs	10 25	R S	R* S	R* S	R* S	R* MR	R* MR	R* R*	R R*	R S	R* R*	R* R*	R S
WBRS-93-69	Brigadier Suffolk	10 25	R* S	S S	R S	R S	R* MR	R* MR	R* R	R -	R MS	R* R	R* R	R S
WBRS-93-80	Estica Oxon	10 25	R* S	S S	R R	R* R	S S	S S	S S	R S	R* R*	R S	MS S	R* S
WBRS-93-87	Hereward Cambs	10 25	S S	S S	R* S	R* S	R* R*	R* R*	R* R*	S S	S S	R* R*	R* R*	R S
WBRS-93-56	Hunter Kent	10 25	S S	S S	MR S	MR S	S S	S S	S S	S S	S S	S S	MS S	R* S

Reaction type assessed on 1 plant
S = susceptible R = resistant
MS = mixed susceptible MR = mixed resistant
R* = resistant, but low levels of type 3/4 pustules

BROWN RUST OF WHEAT ADULT PLANT TESTS AT NIAB

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Spreader beds of winter and spring wheat cultivars were inoculated with four isolates of wheat brown rust as part of the Recommended List testing programme, funded by the Home-Grown Cereals Authority. The isolates were the same as those used in 1992 (Mitchell, 1993). Results for winter wheat are given in Table 1, and for spring wheat in Table 2.

Table 1. Reactions of winter wheat cultivars to infection with four isolates of brown rust in spreader beds at NIAB in 1993.

	% Infection with brown rust *			
Cultivar	WBRS-87-7	WBRS-90-9	WBRS-91-65	WBRS-91-67
Slejpner	3	6	8	2
Beaver	11	14	13	4
Haven	21	21	22	14
Apollo	5	2	4	6
Admiral	8	2	5	4
Soissons	0	0	0	2
Pastiche	0	0	0.2	0.2
Norman	6	1	0.2	5
Buster	6	3	6	15
Avalon	7	9	10	7
Mercia	6	6	4	2
Riband	8	5	5	11
Rialto	15	29	22	11
Hereward	0	0.2	0.2	4
Hussar	0	0	0	0
Andante	0	0	0	0
Lynx	0	0	0	0
Prophet	0	0	0	0
Flame	0	0	0.2	0
Torfrida	0	0	0	0
Estica	0	0	0	0
Brigadier	0	0	0	0
Cadenza	0	2	3	1
Genesis	0	0.2	0.2	0
Hunter	0	0	0	0
Spark	0.2	7	4	6
Zodiac	0.3	7	3	0.2
Virtue	0	0	0	8

* Mean of two replicates assessed three times

Table 2. Reactions of spring wheat cultivars to infection with four isolates of brown rust in spreader beds at NIAB in 1993

Cultivar	% Infection with brown rust *			
	WBRS-87-7	WBRS-90-9	WBRS-91-65	WBRS-91-67
Tonic	28	51	44	35
Alexandria	27	14	28	29
Canon	0	0	0	6
Baldus	4	0	0	0
Rascal	9	5	1	6
Axona	0	0	0	0
Avans	0.2	4	33	12
Promessa	0	0.2	0	0
Sampan	0	0	3	0

* Mean of two replicates assessed three times

In general the results are similar to those reported for the same isolates in 1992 (Mitchell, 1993). However, isolate WBRS-91-65 gave lower levels of infection on Apollo and Admiral than in 1992, and did not significantly infect Pastiche and Soissons. In 1992, Soissons was extremely susceptible to this isolate. WBRS-91-65 was isolated from Pastiche in 1991, and was the first isolate to show virulence for this cultivar.

WBRS-91-67 gave high levels of infection on Buster in both 1992 and 1993, and caused moderate infection of Virtue, its source cultivar. In 1993, this isolate was also virulent on Hereward.

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MILDEW OF BARLEY

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Virulence factors corresponding to widely used specific resistance genes were mostly recorded at high frequencies, as in previous recent surveys. Virulence for BMR9 (*mlo*) was not detected. The barley mildew population has maintained a high level of complexity, and in 1993 most isolates carried at least 5 resistance factors. For the first time, all isolates were tested for BMV11, and this virulence factor was detected at a low frequency, even though the corresponding resistance gene (*Mla3*) has not been used in commercial cultivars in the U.K.

INTRODUCTION

Recent surveys of barley powdery mildew have detected a high frequency of most of the virulence factors corresponding to the specific resistance genes used in commercial winter and spring barley cultivars (Mitchell & Slater 1993, 1992). Mildew resistance factor 9 (*mlo*) is a notable exception and remains effective.

The aims of the 1993 survey of barley mildew were:

1. To monitor changes in the frequencies of virulence factors and combinations of virulence factors corresponding to the specific resistance genes used in commercial and near-commercial cultivars.
2. To determine the specific resistance of new cultivars.
3. To use the frequencies of virulence combinations to compile the variety diversification scheme.

METHODS

Single colony isolates of barley powdery mildew were derived from samples of infected leaves, mostly from Recommended List trials. Random samples of airborne spores were made in March, June and October by exposing seedlings of Golden Promise on a high roof at NIAB, Cambridge. Golden Promise has none of the specific resistance genes used in barley cultivars in the U.K. and should be susceptible to all isolates of mildew.

Isolates from infected leaves were mostly from variety trials at 9 sites:

Bridgets, Hampshire	17 isolates	Headley Hall, Yorkshire	92 isolates
Wye, Kent	23	Cockle Park, Northumberland	53
NIAB, Cambridge	78	Dundee, Scotland	22
Market Stainton, Lincs	4	Tayside, Scotland	18
Trawsgoed, Dyfed	18		
		Total	323 isolates

The source cultivars were:

<u>Winter cultivars</u>

Halcyon	6	isolates	Target	2	isolates	Puffin	7	isolates
Bronze	4		Finch	4		Firefly	10	
Intro	4		Gaelic	12		Marinka	4	
Gaulois	2		Kira	6		Fighter	16	
Pastoral	4		Epic	6		Fakir	7	
Chestnut	1		Torrent	4		Manitou	6	
Linnet	5		Silk	2		Pipkin	4	
Sprite	6		Willow	4		13 cv. of unknown resistance	23	
Swift	4							

<u>Spring cultivars</u>

G. Promise	23	isolates	Delibes	14	isolates	Forester		isolates
Doublet	2		Felicie	12		Juno	5	
Triumph	2		Nomad	2		Camargue	12	
Blenheim	7		Apex	10		Tyne	7	
Prisma	2		Atem	1		Goldie	4	
Cooper	12		Dandy	1		Ricardo	1	
Chad	4		Hart	2		14 cv. of unknown resistance	28	
Brewster	14		Heron	4				

A further 25 samples of infected leaves failed to produce viable isolates of mildew.

Table 1. Differential cultivars used to determine virulence factors in barley mildew in 1993.

BMR group	European code	Resistance gene	Cultivar
0	0	none	Golden Promise
1a	Ha	*Mlh*	Weihenstephan 37/136
1b	Ra	*Mlra*	Weihenstephan 41/145
2a	We	*Mlg*	Goldfoil *
2a,2b	We	*Mlg, Ml(CP)*	Zephyr
3	Sp	*Mla6, Mla14*	Midas
4	La	*Ml(La)*	Lofa Abed
5	Ar	*Mla12*	Hassan
6a	Kw	*MlK*	Hordeum 1063
6b	Ly	*Mla7*	Porter
6c	Ab	*Ml(Ab)*	Lotta
6b,6c	Ly, Ab	*Mla7, Ml(Ab)*	Triumph
7	Al	*Mla1*	Tyra
8	MC	*Mla9*	Roland *
6a,8	Kw, MC	*MlK, Mla9*	Simon
9	Mlo	*mlo*	Apex
10a	Ru	*Mla13*	Digger
11	Ri	*Mla3*	Ricardo

* Isolates were tested on Goldfoil and Roland only when tests on other differential cultivars did not identify all virulence factors.

Isolates were tested for virulence on detached leaves of the differential cultivars listed in Table 1. Virulence was determined according to the infection types of Moseman *et al.* (1965).

RESULTS

Virulence

The frequencies of barley mildew virulence factors (BMV) 1a, 1b, 2a, 2b, 3, 4, 5, 6a, 6b, 6c, 7, 8, 10 and 11 in the sample from infected leaves (leaf sample) and random samples of airborne spores are given in Table 2. For the leaf sample, results are also given for non-corresponding virulence, where those virulences in individual isolates which correspond to the resistance in the host cultivar have been excluded from the data. This gives some indication of the influence of host resistance on the virulence frequencies.

Table 2. Frequency of virulence factors in isolates of barley mildew from infected leaves (leaf sample) and in random samples of single colony isolates formed from airborne spores in 1993.

	Frequency of virulence factors (%)				
	Leaf sample		Random samples of airborne spores		
Virulence factor	All data	Non-corresponding virulence *	March	June	October
1a	84	81	73	84	59
1b	100	100	100	100	100
2a	99	99	93	96	91
2b	97	97	88	92	81
3	50	47	28	18	14
4	29	25	19	18	13
5	82	83	66	73	44
6a	74	74	79	71	82
6b	78	76	84	83	57
6c	79	75	66	83	71
7	27	18	8	9	7
8	33	29	21	18	39
10	26	22	39	43	72
11	1	0	1	0	0
Number of isolates	323		102	103	100

* Includes virulence factors only where they did not correspond with the resistance factors of the host cultivar.

Most of the virulence factors were recorded at high frequencies, particularly those which correspond to resistance factors which have been widely used in the U.K. for a number of years (BMV1a, 1b, 2a, 2b, 5, 6a, 6b, and 6c). This was the first year in which all isolates were tested on the BMR11 differential cultivar Ricardo, and BMV11 was recorded at a very low frequency. The corresponding resistance has not yet been used in commercial cultivars in the U.K. None of the 24 isolates from cultivars with BMR9 (source cultivars Apex, Atem, Dandy, Hart, Heron, Forester and Juno) were virulent on the BMR9 differential cultivar.

Compared to 1992, the frequency of BMV3 in the leaf sample showed a sharp increase. This cannot be explained by changes in the popularity of cultivars with BMR3, principally the winter cultivars Kira and Torrent which are no longer widely grown. The frequencies of BMV4 and BMV10 decreased slightly in most samples compared to 1992. This may reflect the declining popularity of Tyne (BMR4,10), although Pipkin (BMR10) remains a popular winter cultivar. BMV7 has increased in frequency as a number of spring cultivars with the corresponding resistance have become more widely grown.

Only BMV7 was recorded at a lower frequency as non-corresponding virulence compared to the whole data set. This suggests that there is some host selection for BMV7, but very little for other virulences.

Complexity of Isolates

Table 3 shows the number of virulence factors carried by isolates in the leaf sample and random samples of airborne spores. Most of the isolates carried 5 or more virulence factors, and there was little difference between the samples. In 1991 and 1992, most isolates in the leaf samples carried 7 or more virulence factors, and in the random samples of airborne spores most isolates carried 5 or more factors.

Table 3. Number of virulence factors (BMV1a, 1b, 2a, 2b, 3, 4, 5, 6a, 6b, 6c, 7, 8 and 10) carried by isolates of barley mildew in 1993.

No. of BMV factors	Frequency of isolates with each number of virulence factors			
		Random samples of airborne spores		
	Leaf samples	March	June	October
0	0	0	0	0
1	0	0	0	0
2	0	1	0	0
3	0	1	0	0
4	2	5	6	9
5	14	21	20	26
6	30	38	42	38
7	30	25	26	23
8	14	8	6	5
9	7	1	1	0
10	2	0	0	0
11	1	0	0	0
12	0	0	0	0
13	0	0	0	0
No. of isolates	323	102	103	100

Frequencies of Pathotypes

The frequencies of the most common pathotypes are given in Table 4. Most of these pathotypes have been recorded at similar frequencies in previous years. Pathotypes BMV1a,1b,2a,2b,3,5,6a,6b,6c and BMV1a,1b,2a,2b,3,5,6b,6c,7 and other combinations of BMV1a,1b,2a,2b,5,6b,6c were recorded at higher frequencies this year compared to 1992. The common pathotypes with BMV10 were generally less frequent this year than in 1992. Other pathotypes were recorded at low frequency, occurring only once or twice in each sample.

Table 4. Frequencies of the most common barley mildew pathotypes identified in 1993, defined by BMV1a, 1b, 2a, 2b, 3, 4, 5, 6a, 6b, 6c, 7, 8 and 10.

	Frequency of pathotypes (%)			
		Random samples of airborne spores		
Pathotypes *	Leaf samples	March	June	October
5 6b 6c	5	3	5	1
5 6a 6b 6c	9	13	12	3
3 5 6b 6c	5	5	5	1
3 5 6a 6b 6c	7	6	2	1
3 5 6b 6c 7	6	0	0	1
6a 6b 6c 10	1	2	5	4
5 6a 6b 6c 10	<1	3	8	3
6a 6b 8 10	1	2	1	2
6a 6b 6c 8 10	1	1	3	5
Total no. of pathotypes	131	60	55	71
Total no. of isolates	323	102	103	100

* All of these pathotypes also carry BMV1a, 1b, 2a and 2b.

Resistance Factors in New Cultivars

The resistance factors of cultivars included in the Barley Mildew Variety Diversification Scheme, and of U.K. Recommended List Candidates tested in 1993, are given in Table 5.

Table 5. Specific resistance factors of barley cultivars.

BMR0		**BMR10**		**BMR4,10**	
Halcyon	(W)	Camargue	(S)	Tyne	(S)
		Pipkin	(W)		
BMR1b				**BMR5,6c**	
Bronze	(W)	**BMR1b,3**		Blenheim	(S)
Chestnut	(W)	Gaelic	(W)	Prisma	(S)
Gaulois	(W)				
Intro	(W)	**BMR1,2,3**		**BMR6c,7**	
Linnet	(W)	Epic (?1b)	(W)	Brewster	(S)
Pastoral	(W)	Kira (?1b)	(W)	Chad	(S)
Princess	(W)	Torrent (?1b)	(W)	Delibes	(S)
Sprite	(W)				
Swift	(W)	**BMR1a,5**		**BMR4,7**	
		Silk	(W)	Cooper (?+6c)	
BMR1a,1b		Willow	(W)		
Finch	(W)			**BMR6c,8**	
Target	(W)	**BMR1,2,5**		Nomad	(S)
		Puffin (not 1b)	(W)		
BMR2		Firefly	(W)	**Unknown**	
Gypsy (2a,?2b)	(W)			Goldie	(S)
		BMR1,6b			
BMR8		Marinka	(W)		
Fakir (?+1,2)	(W)				
Manitou	(W)	**BMR2a,2b,8**			
		Felicie	(S)		
BMR9					
Alexis	(S)	**BMR2,6c**			
Chariot	(S)	Fighter (?+1b)	(W)		
Dandy	(S)				
Derkado	(S)				
Hart	(S)				
Heron	(S)				
Juno	(S)				

(W) winter cultivar, (S) spring cultivar

Tests for Sensitivity to Fenpropimorph

A sample of 49 isolates collected in 1993 was tested for sensitivity to fenpropimorph. A single test with six replicates was carried out on detached leaf segments from seedlings sprayed with various rates of the fungicide. The results are summarised in Table 6, with data from similar tests carried out in 1991. Direct comparisons between the two tests cannot be made, but within each test the isolates can be compared to the control isolates. In 1991 and 1993 many of the isolates were less sensitive than the moderately insensitive control isolates, but there is no indication from these tests of a change in sensitivity from 1991 to 1993.

Table 6. Sensitivity of barley mildew to fenpropimorph.

Sample (no. of isolates)	Growth as % of growth on untreated leaves Rate of fenpropimorph as proportion of field rate 0.01	0.02	0.05	0.10
1993				
Cambridge, June* (10)	7	0	0	0
Cambridge, Oct* (12)	28	16	6	0
Cambridge (9)	7	3	0	0
Headley Hall (11)	34	31	1	0
Scotland (11)	38	14	3	0
Sensitive controls (3)	0	0	0	0
Slightly insensitive (1)	9	0	0	0
Moderately insensitive (2)	50	40	3	0
1991				
East Anglia (10)	26	0	0	0
Dundee (10)	37	20	13	0
Sensitive controls (3)	41	3	0	0
Moderately insensitive (3)	103	100	63	24

* From random samples of airborne spores

CONCLUSIONS

1. Virulence factors corresponding to widely used specific resistance genes were again recorded at high frequencies. Since most isolates carry at least 5 virulence factors most combinations of specific resistance factors are largely ineffective.
2. The high level of complexity in the barley mildew population reduces the opportunities for variety diversification.
3. BMR9 (*mlo*) remains effective. Varieties with this resistance gene accounted for 69% of the U.K. spring barley seed crop in 1993, and continue to increase in popularity.

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MILDEW OF BARLEY IN NORTHERN IRELAND

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The single virulence 7 increased markedly, possibly due to an increase in popularity of Chad (BMR 6c+7). Unlike in Britain, BMV 10 did not increase, while the combined virulence 4+10, isolated at a very low frequency in 1992, was not isolated at all in 1993. The recent trend in resistance to Baytan seed-treatment appeared to be levelling off.

Forty-six isolates were tested during the year and their distribution across varieties is indicated in Table 1. The cultivars used for the testing of virulences of the isolates are shown in Table 2, while the most commonly sown barley cultivars in N. Ireland in the previous season, 1991/92, are shown in Table 3.

Table 1. Sources of mildew isolates tested in 1993

BMR group	Isolate source	No. isolates
0	Pastoral	13
1b	Chestnut	2
	Sprite	1
9	Derkado	3
10	Pipkin	1
2 + 6c	Fighter	4
4 + 10	Tyne	3
5 + 6c	Prisma	2
6c + 7	Chad	8
1 + 2 + 3	Kira	7
	Torrent	1
1 + 2 + 5	Puffin	1

As suggested in the previous report, the safest comparisons are probably of patterns for individual years, rather than of yearly changes in absolute frequencies. The frequencies of the single major genes 2, 3, 4 & 5 (Table 4) were generally higher than in 1992, particularly with BMR 4 and BMR 5. Frequencies of the combined virulences 6a + 6b and 6b + 6c were slightly higher than in 1992, but probably not significantly so. The frequency of BMV 7 was, however, considerably higher, possibly due to the increasing popularity of Chad (BMR 6c + 7). This is in line with English, but not Scottish experience (Mitchell & Slater, 1994;

Table 2. Test cultivars for the detection of virulence groups.

BMR group[1]	Cultivar
0	Golden Promise
2	Zephyr
3	Midas
3 + 4	Goldspear
4	Varunda
4 + 5	Egmont
4 + 6a	Dram
4 + 6a + 6b	Klaxon
4 + 9	Atem
4 + 10	Tyne
5	Hassan
6a + 6b	Keg
6b + 6c	Triumph
7	Delta
8	Leith
10	Digger

[1]for European codes and resistance genes see Mitchell & Slater, 1994.

Table 3. Percentage use of barley cultivars in N. Ireland (1991/92)

Spring cultivars		Winter cultivars	
Dandy	26	Pastoral	38
Chad	21	Torrent	23
Tyne	15	Kira	18
Nugget	11	Gypsy	6
Blenheim	5	Marinka	5
Alexis	5		

(Newton, 1994). The frequency of BMV 8 appears fairly stable, although there are no popular cultivars carrying the corresponding resistance gene. All the combined virulence groups BMVs 3 + 4, 4 + 5, 4 + 6a and 4 + 6a + 6b were relatively lower than in the previous season, possibly because of declines in the popularity of cultivars carrying the corresponding groups of resistance genes. BMR 4 + 9 continues to show complete resistance, even though Dandy (BMR 9) was the most popular cultivar. The levelling-off in frequency of BMV 10, which had been noted in 1992, was evident again in 1993. This is in contrast to both English and Scottish experience (Mitchell & Slater, 1994; Newton, 1994). However, BMV 4 + 10, tested for the first time in 1992 when it showed a very low frequency, did not register at all in 1993 even though Tyne (BMR 4 + 10) continued to be a popular cultivar.

Table 4. Frequencies of virulence alleles from isolates collected from infected leaves from 1990- 1993.

Virulence	Frequency of virulence allelles (%) 1990	1991	1992	1993
2	43	64	39	43
3	41	54	36	47
4	27	57	25	47
5	46	54	31	67
6a + 6b	48	57	31	37
6b + 6c	33	71	36	47
7	20	14	14	40
8	27	30	28	30
3 + 4	67	39	36	30
4 + 5	27	50	47	30
4 + 6a	50	50	44	30
4 + 6a + 6b	59	41	44	27
4 + 9	0	0	0	0
4 + 10	n.a.	n.a.	3	0
10	14	46	25	27

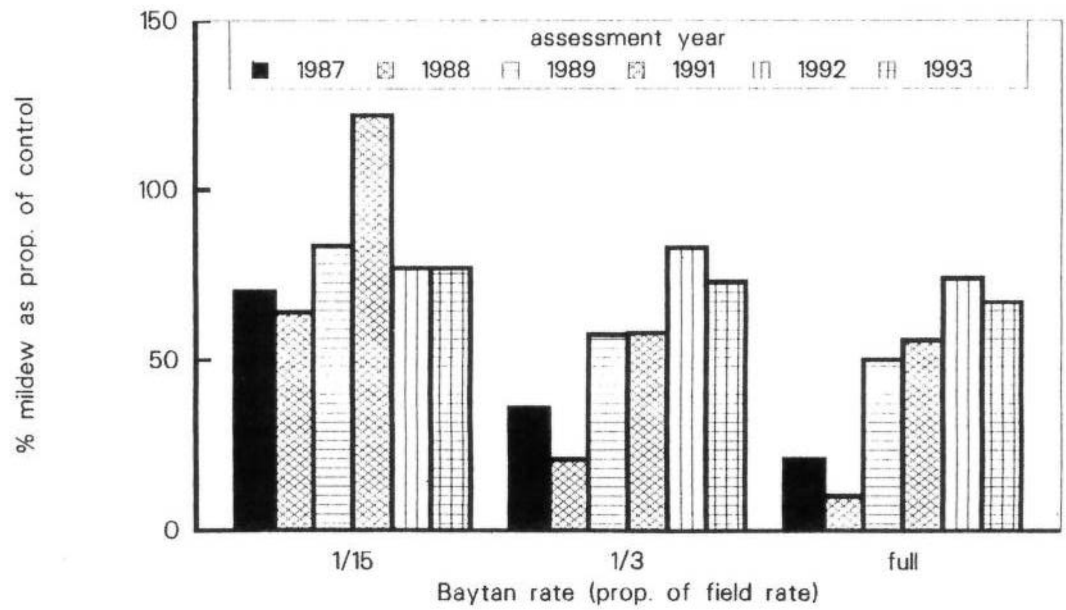

Fig. 1 Percentage of colonies of mildew growing on Baytan-treated seedlings as a proportion of those on untreated seedlings

Tests continued on the effectiveness of Baytan seed-treatment. Results (Fig. 1) showed that the trend towards increased resistance seen in recent years had levelled off, effectiveness being at a similar level to the previous year.

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MILDEW OF BARLEY IN SCOTLAND (SCRI)

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Barley mildew surveyed in Tayside had a higher frequency of BMV groups 4, 8 and 10 than NIAB samples but reduced frequency of BMV6b+c and 7. These differences are partly explained by the popularity of Camargue in Scotland.

INTRODUCTION

Mobile nurseries consisting of 12 differentials (Table 1) were exposed on five dates at each of two locations at SCRI, one 500 metres from the nearest barley and protected by buildings, the other surrounded by plots of Triumph and Dallas in a field experiment.

Table 1. Differential cultivars used to determine virulence factors in 1993.

BMR group	Source	Resistance allele	Cultivar
0	-	a8	Pallas
1a	Ha	h	-
1b	Ra	ra	-
2a,2b	We	g+(CP)	P21
3	Sp	a6	P03
4	La	(La)	P23
5	Ar	a12	P10
6a	Kw	k	P17
6b+6c	Ly+Ab	a7+(Ab)(Tr3)	Triumph
7	Al	a1	P01
8	MC	a9	P8b
9	Mlo	o5	-
10	Ru	a13	P11
11	Ri	a3	-
SCRI1	Ly	a7+(Mu2)	P06
SCRI2	-	(Ru2)	P15

RESULTS

Table 2. Frequency of virulence factors in SCRI populations of mildew expressed as colony frequency relative to cv. Pallas.

	All data			
	SCRI	NIAB	SCRI field	SCRI bldg
2a+b	92	98	94	79
3	62	50	**65**	**32**
4	**65**	**29**	65	**65**
5	90	82	92	80
6a	61	74	59	65
6b+c	84	**79**	**90**	**30**
7	11	**27**	11	**5**
8	**83**	**33**	87	45
10	**91**	**26**	96	39
SCRI1	69	-	**73**	**30**
SCRI2	76	-	75	85

Underlined numbers in table 2 highlight the main comparisons of interest. There is a greater frequency of BMV4 (Ml(La)) BMV8 (Mla9) and BMV10 (Mla13) in the SCRI than the NIAB population comparing the overall data in columns two and three. However, the better comparison is between columns three and five where the direct influence of adjacent barley is removed. Here we see the same enhancement of BMV4 but a much reduced frequency of BMV6b+c (Mla7+(Ab)(Tr3)) and BMV7 (Mla1), and BMV 8 and 10 show less enhancement in this population than the overall SCRI population. These differences probably reflect the popularity of the Mla13 cultivar Camargue in Scotland.

The greater frequency of Mla7+(Ab)(Tr3) in the 'SCRI field' is probably attributable to the close proximity of Triumph, so presumably the other greater frequencies are attributable to Dallas (Mla12? + Mla13? +?) and to genes hitch-hiking with Mla7 + (Ab)(Tr3), ie. Mla7+(Mu2) Mla9, Mla13 and Mla6.

YELLOW RUST OF BARLEY

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One isolate possessing BYV 1,2 was received in 1993.

INTRODUCTION

The specific resistances (BYR factors) identified in barley cultivars to date, differential cultivars possessing each resistance and the year of first detection of corresponding virulence in the UK population of *P. striiformis* are given in Table 1.

Table 1 Resistance factors to *Puccinia striiformis* and differential cultivars

BYR Factor	Type*	Differential Cultivars	BYV detected
BYR 1	O	Astrix, Atem	1960
BYR 2	O	Bigo, Varunda	)
			)1972-1975
	S	Mazurka	)
BYR 3	?S	Triumph	1983

* O = Overall, S = Seedling. Overall resistances are effective at all growth stages, seedling resistances are ineffective at adult plant growth stages.

METHODS

<u>Seedling test with 1993 isolate</u>

One sample was received from South Humberside from a UK National List winter barley cultivar.

The sample was tested in a seedling test using the methods described by Priestley, Bayles and Thomas (1984).

RESULTS

Virulence frequencies for 1978-1993 are shown in Table 2.

Table 2 Virulence factor frequency (%)

	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93
BYV 1	98	100	100	100	100	100	100	-	-	100	-	100	100	100	100	100
BYV 2	32	0	54	81	96	87	100	-	-	100	-	100	0	100	100	100
BYV 3/	-	-	-	-	-	17	86	-	-	22	-	75	0	0	0	0
Number of isolates	44	1	56	52	25	30	7	0	0	9	0	4	1	1	2	1

/ Not included in tests before 1983.

The 1993 isolate was virulent on the BYV 1 differentials Astrix and Atem and the BYV 2 differentials Bigo and Varunda.

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BROWN RUST OF BARLEY

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Seedling tests on 18 isolates cultured from selected leaf samples identified 3 previously detected races. Within the field isolation nurseries, the winter barleys displayed a range of quantitative responses with some cultivars showing good levels of resistance. Cultivar/pathogen interactions enabled the spring barleys to be grouped on the basis of similarities in their patterns of response.

GLASSHOUSE SEEDLING TESTS WITH 1993 ISOLATES

One hundred and nineteen samples of barley brown rust were received in 1993. This number included 50 sent from the CSL/ADAS Cereal Disease Survey. One hundred and twelve of the samples were from a range of winter barley cultivars, with 6 coming from spring barleys and 1 of unknown origin. The geographic origins of the samples are given in Table 1.

Table 1. Geographical location of 1993 barley brown rust samples

Location		Number of samples
England (ADAS region)		
	East-central	54
	East	34
	North	11
	South-west	10
	South	5
	West-central	2
Wales		3

Isolates of *Puccinia hordei* cultured from 18 of the samples, which were selected on the basis of cultivar or geographic origin, were tested on the standard set of 10 differential cultivars (Table 2).

Table 2. 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}	10

<u>Results</u>

The virulence combinations identified in the 18 isolates and their octal designations are given in Table 3.

Table 3. Races identified from 1993 isolates

Number of isolates	Octal designation	BBV factors
15	1673	1,2,4,5,6,8,9,10
2	1677	1,2,3,4,5,6,8,9,10
1	677	1,2,3,4,5,6,8,9

Fifteen of the isolates were identified as race octal 1673, the prevalent race in recent years. Virulence to the differential cv. Ribari (BBR-3) was detected in 3 of the isolates. Two of these, cultured from leaf samples of cv. Marinka sampled in Sussex, were identified as race octal 1677 - a widely virulent race which fails only to overcome the resistance of the differential cv. Cebada Capa (BBR-7). The other Ribari-virulent isolate, race octal 677, was sampled from a disease nursery into which an isolate carrying the same virulence factors (BBV-1,2,3,4,5,6,8,9) had been artificially introduced.

ADULT PLANT TESTS IN FIELD ISOLATION NURSERIES

Twenty-five winter and 24 spring barley cultivars were sown in each of two nurseries in the 1992-1993 season. One was inoculated with race octal 1653 (BBV-1,2,4,6,8,9,10) and the other with race octal 677 (BBV-1,2,3,4,5,6,8,9).

<u>Results</u>

Winter barleys: The spreader cultivar within the winter barley nurseries became heavily infected with *Rhynchosporium*. This resulted in a slow build-up of brown rust inoculum for the test cultivars, and also in the *Rhynchosporium*-susceptible varieties within the nurseries becoming heavily infected with leaf blotch. Assessment of the amount of brown rust on some of the cultivars was thus rendered difficult. Also, disease levels appeared to be generally lower within the nursery inoculated with race octal 677. The percentage levels of infection recorded in Table 4 should therefore be interpreted with caution. The cultivars displayed a range of quantitative responses within both nurseries. With a few exceptions, cultivar rankings between nurseries followed a similar pattern. Cultivar Torrent displayed lower levels of disease within the nursery inoculated with race octal 677 than that inoculated with race octal 1653, whereas the converse was true of cv. Clarine. Previous years' results suggest that neither of these cultivars carries a specific resistance effective against either of these isolates. Several of the cultivars expressed resistance to both isolates.

Spring barleys: These have been grouped on the basis of similarities in their patterns of response to the 2 isolates (Table 5). Cultivars within the first group are susceptible to both isolates although quantitative differences in susceptibility are apparent. Cultivar Midas is known not to carry any resistance. Previous years' results indicate that cvs Blenheim and Prisma share a common resistance with cv. Triumph (BBR-10). The pedigree of cv. Camargue suggests that it may also carry this resistance. Although cv. Triumph was less heavily infected within the nursery inoculated with race octal 677, which does not carry the corresponding virulence factor BBV-10, it is difficult to explain why cvs Blenheim, Prisma and Camargue showed comparable disease levels within the two nurseries. Cultivars Hart, Dandy and Armelle are also placed in this group as they showed a similar pattern of response to the isolates, although the pedigrees of the former 2 cultivars suggest that any resistance may be derived from cv. Vada which carries a non-specific resistance.

Cultivars within the second group displayed a susceptible reaction of a mixed type to the isolates, but did not show the high levels of infection of some of the group 1 varieties.

The resistance of cultivars within the third group was effective within both nurseries although quantitative differences in levels of infection were apparent.

Cultivar Simon (BBR-3) was resistant to race octal 1653 but susceptible to race octal 677 which carries the corresponding virulence gene (BBV-3).

Table 4. Percent infection* of winter barley cultivars with specific isolates of *P. hordei* Otth. in field isolation nurseries in 1993

Winter Cultivar (NIAB rating)		Race octal 1653 (BBV-1,2,4,6,8,9,10)		Race octal 677 (BBV-1,2,3,4,5,6,8,9)	
Target	(5)	20		14	
Torrent		20		6	
Marinka	(6)	19		17	
Manitou	(5)	15	MS	13	MS
Fakir		14		12	
Pipkin	(6)	13		9	
Chestnut		8		3	
Gypsy		7		2	
Pastoral	(5)	6		6	
Kira		5		5	
Gaelic	(8)	5		5	
Linnet	(8)	5	MS	0.5	
Clarine		4		12	
Firefly	(8)	3	MS	3	
Halcyon	(7)	3		2	
Gaulois		3		2	
Epic	(7)	2		5	
Bronze	(7)	2		5	
Sprite	(7)	2		2	
Fighter	(7)	2		0.3	
Puffin	(8)	1		6	
Intro	(8)	0.3		1	
Finch		0.2	MS	3	
Swift		0.1	MS	0.3	
Willow	(8)	0.1	MR	0.2	MS

* Mean of 4 replicates, final assessment date
( ) NIAB rating: 1 = susceptible, 9 = resistant
All reaction types susceptible unless stated
MS = mixed susceptible MR = mixed resistant

Table 5. Percent infection* of spring barley cultivars with specific isolates of *P. hordei* Otth. in field isolation nurseries in 1993

Cultivar (NIAB rating)		Group	Race octal 1653 (BBV-1,2,4,6,8,9,10)		Race octal 677 (BBV-1,2,3,4,5,6,8,9)	
Midas			30		35	
Blenheim	(5)		25		23	
Prisma	(4)		23		16	
Triumph	(5)	1	23		9	MS
Camargue	(7)		17		13	
Hart	(3)		12		20	
Armelle			11		20	
Dandy	(3)		10		21	
Chariot	(4)		12	MS	14	MS
Nomad	(5)		11	MS	20	
Tyne	(6)		10	MS	13	MS
Heron	(8)	2	8	MS	11	MS
Felicie	(5)		7	MS	14	MS
Juno			7	MS	8	MS
Vada			7	MS	14	
Alexis	(5)		3	MS	16	MS
Derkado	(7)		12	MR	8	MR
Brewster	(8)		8	MR	10	MR
Chad	(8)	3	6	MR	2	MR
Cooper	(8)		4	MS	1	MR
Corniche			3	MR	0.5	MR
Delibes	(9)		3	R	0.5	R
Goldie			Trace	R	1	R
Simon		4	0.1	MS	20	

* Mean of 4 replicates, 2 assessment dates
( ) NIAB rating: 1 = susceptible, 9 = resistant
All reaction types susceptible unless stated
MS = mixed susceptible MR = mixed resistant R = resistant

RHYNCHOSPORIUM OF BARLEY

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One new race, designated Octal 74 was found in 1 isolate. It poses no new threat as the virulence factors carried by this isolate have previously been identified in combination with additional virulences in more complex races. Within the field isolation nurseries, some of the winter barley cultivars displayed good levels of resistance to the pathogen. The resistance of the spring barley cv. Digger remains effective.

SEEDLING TESTS WITH 1993 ISOLATES

The 92 samples of leaf blotch received in 1993 were from a wide range of barley cultivars. Half were sampled from winter cultivars, 45 from spring barleys and 1 of unknown origin. The bulk of the samples came from three trial centres, Cockle Park, Northumberland (34), Headley Hall, Yorkshire (15), and SCRI, Tayside (15). Thirteen isolates received from Queen's University, Belfast, were included in the tests. These isolates had been cultured from leaf samples taken from field crops prior to the 1992 harvest. The geographic origins of the samples are given in Table 1.

Table 1. Geographic origin of *Rhynchosporium* samples received in 1993

Location	Number of samples
England (ADAS region)	
North	34
East-central	15
East	11
South-west	1
Scotland	16
Northern Ireland	13
Wales	2

Sixty-nine isolates were successfully tested on a set of differential cultivars carrying resistances of relevance to UK agriculture, together with additional winter and spring barleys. Test cultivars and their resistance factors are given in Table 2.

Table 2. Differential test cultivars for *Rhynchosporium secalis*

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

Results

The isolates tested gave a range of different virulence combinations when classified by their reactions on the standard set of differential cultivars. Each virulence combination identified has been designated by an octal virulence number (Table 3).

Table 3. Virulence factor combinations identified from the 1993 survey

No. of isolates	Differential cultivars in fixed linear order							Race octal
	Pirate	Osiris	La Mesita	Igri	Athene	Astrix	Armelle	
22	0	0	0	1	1	1	1	17
20	1	0	0	1	1	1	1	117
10	1	0	0	1	1	0	0	114
5	0	0	0	1	1	0	0	14
2	1	0	0	0	1	1	1	107
2	1	0	1	1	1	1	1	137
2	1	1	1	1	1	0	0	174
1	0	0	0	0	1	0	0	4
1	1	0	0	0	1	0	0	104
1	1	1	1	0	1	0	0	164
1	1	0	1	1	1	0	0	134
1	0	1	1	1	1	0	0	74
1	0	1	1	1	1	1	1	77

1 = susceptible 0 = resistant

One new combination, race octal 74, was identified in 1993. Isolates combining virulence factors 3,4,5,6 have previously been detected but only in more complex combinations, most commonly with BRV-7.

Virulence to cv. Osiris (BBR-6) was detected in 5 of the 1993 samples. These 5 isolates also carried virulence to cv. La Mesita (BRR-5) in common with all previously identified Osiris-virulent isolates. Three of the 5 isolates, RS-93-55 (race octal 164), RS-93-56 (race octal 174) and RS-93-58 (race octal 77) came from a site in Spalding, Lincs. The others, RS-93-65 (race octal 174) and RS-93-2 (race octal 74) were from Headley Hall, near Leeds, and Co. Down, respectively. Three additional isolates identified as races octal 137 and 134, carried virulence to cv. La Mesita (BBR-5) but not cv. Osiris, these also being from cultivars sampled at Spalding, Headley Hall, and Co. Down respectively. None of these samples was from cv. Pipkin which is the only currently-grown commercial variety known to carry resistance factor BRR-5 derived from cv. La Mesita. A small area of cv. Pipkin had previously been grown near to the site in Spalding, and infected volunteers of this cultivar may have been the source of inoculum for the samples received from this location.

Frequencies of virulences (Table 4) to cvs Armelle (BBR-1) and Astrix (BBR-2) were at an increased level in 1993. These data should, however, be treated with caution as 30% of the isolates successfully tested in 1993 came from one site (Cockle Park, Northumberland). With the exception of 1 isolate, all were identified as carrying virulence factors 1 and 2. Virulence to La Mesita (BBR-5) and Osiris (BBR-6) remain at low levels.

The resistance of the spring barley cv. Digger continues to be effective although, as in previous years, several isolates induced low infection levels (2%-5%). No samples were received from this cultivar.

Table 4. Frequencies of individual virulences, 1988-1993

	BRV-							No. of isolates
	7	6	5	4	3	2	1	
1988	0.81	0	0	0.98	0.98	0.19	0.19	48
1989	0.54	0.08	0.23	0.92	0.92	0.62	0.62	15
1990	0.54	0.23	0.30	0.76	0.92	0.23	0.23	13
1991	0.28	0	0	0.52	0.74	0.22	0.22	50
1992	0.50	0.07	0.10	0.86	0.97	0.40	0.40	30
1993	0.57	0.07	0.12	0.94	1.00	0.68	0.68	69

ADULT PLANT FIELD TESTS IN ISOLATION NURSERIES

Thirty-one winter and 24 spring barley cultivars were sown in each of two nurseries in the 1992-1993 season. One nursery was artificially inoculated throughout the season with isolate RS-85-50. This widely virulent isolate carries BRV factors 1,2,3,4,5,6 (race octal 77). The second nursery was grown alongside and received inoculum from a *Rhynchosporium* disease nursery used to screen barley material and which is infected naturally. Leaf samples taken from the nursery during the season were tested on seedlings of the set of differential cultivars. The isolate cultured from the infected leaves collected was identified as race octal 14.

An additional nursery comprising the 24 spring barleys was grown at a site in Mylnfield, Scotland (Dr A. C. Newton). The cultivars in this nursery became infected with naturally-occurring pathotypes.

Results

Winter barleys: Disease was slower to build up in the nursery inoculated with race octal 77 than in the nursery receiving natural inoculum where the susceptible cultivars were heavily infected early in the season. Levels of disease recorded on the cultivars at the final assessment date only are given in Table 5, as this allows a better comparison between nurseries, although disease levels on the susceptible cultivars within the artificially-inoculated nursery were lower. The cultivars displayed a range of quantitative responses within both nurseries with cultivar rankings between nurseries following a similar pattern. Cultivar Pipkin (BBR-5) was highly susceptible (34% leaf area infected) in the naturally-infected nursery (race octal 14), although seedling test results did not confirm that inoculum from this nursery carried BRV-5. This confirms previous observations (Jones and Clifford, 1982) that cv. Pipkin, like cv. La Mesita from which it derives its resistance, is more susceptible at the adult plant stage of growth, even to isolates not carrying the corresponding virulence gene. The low levels of infection (4%) recorded on cv. Pipkin in the nursery into which RS-85-50 was introduced is difficult to explain as this isolate carries the corresponding virulence factor BRV-5. It may be that disease levels built up too late in the season. Several of the winter barleys displayed good levels of resistance.

Spring barleys: As in the winter nurseries, lower levels of *Rhynchosporium* infection were achieved on the susceptible cultivars within the nursery inoculated with the widely virulent isolate RS-85-50 (Table 6). The cultivars expressed quantitative differences in susceptibility to the pathogen in both nurseries. The specific resistances of cvs Armelle (BBR-1) and Osiris (BRR-6) were effective against race octal 14 which does not carry the corresponding virulence factors. Race octal 77 also failed to infect these cultivars, despite carrying virulence factors 5 and 6. The resistance of cv. Digger remained effective in these nurseries, although higher levels of infection (6%) were recorded at Mylnfield. The cultivars also displayed a range of quantitative resistance within this nursery with cultivar rankings showing a similar pattern to those in the other two nurseries.

REFERENCE

Clifford, B.C. and Jones, E.R.L. (1982). *Rhynchosporium* of barley. United Kingdom Cereal Pathogen Virulence Survey 1981 Annual Report, pp.61.64.

Table 5. Percent infection* of winter barley cultivars in *Rhynchosporium* isolation nurseries in 1993

Cultivar (NIAB rating)		Naturally infected (see text)	RS-85-50 (BRV-1,2,3,4,5,6)
Pipkin	(3)	34	4
Willow	(3)	30	8
Intro	(6)	26	7
Finch		25	26
Otter		24	15
Epic	(6)	23	2
Gaelic	(5)	21	11
Swift		16	6
Linnet	(6)	15	4
Fighter	(6)	15	2
Halcyon	(6)	14	1
Firefly	(8)	14	0.3
Puffin	(7)	13	4
Sprite	(8)	13	0.3
Athene		11	5
Kira		11	0.5
Igri		10	5
Marinka	(8)	9	0.1
Bronze	(6)	8	2
Pastoral	(7)	7	1
Clarine		6	2
Torrent		6	1
Astrix		6	0.2
Gaulois		6	0.2
Gypsy		5	2
Hoppel		4	0.4
Target	(8)	4	0.1
Chestnut		3	0.4
Fakir		3	0.3
Pirate		3	0.1
Manitou	(8)	2	0.1

* Mean of 4 replicates, final assessment date
( ) NIAB rating: 1 = susceptible, 9 = resistant

Table 6. Percent infection* of spring barley cultivars in *Rhynchosporium* isolation nurseries in 1993

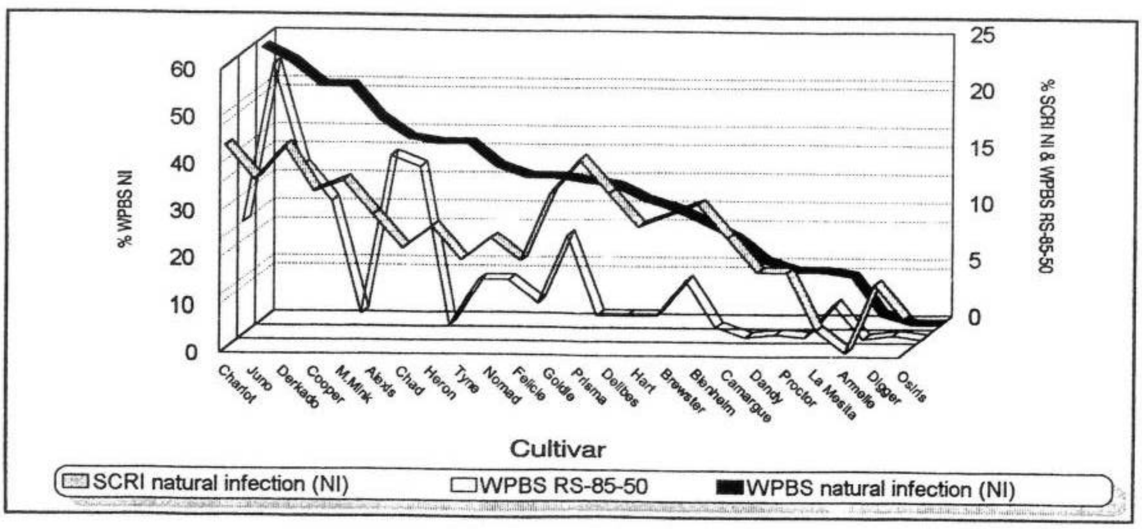
Cultivar (NIAB rating)		WPBS naturally infected* (see text)	SCRI naturally infected# (see text)	RS-85-50* (BRV-1,2,3,4,5,6)
Chariot	(3)	58	18	10
Juno		55	15	24
Derkado	(3)	50	18	15
Cooper	(5)	50	14	12
Maris Mink		43	15	2
Alexis	(4)	39	12	16
Chad	(5)	38	9	15
Heron	(4)	38	11	1
Tyne	(5)	33	8	5
Nomad	(7)	31	10	5
Felicie	(7)	31	8	3
Goldie		30	14	9
Prisma	(6)	29	17	2
Delibes	(6)	26	14	2
Hart	(6)	24	11	2
Brewster	(7)	21	12	5
Blenheim	(7)	18	13	1
Camargue	(7)	13	10	0.1
Dandy	(7)	11	7	0.4
Proctor		11	7	0.1
La Mesita		10	2	3
Armelle		2		Trace
Digger		0.2	6	0.3
Osiris		0.1	3	0

* Mean of 4 replicates, final assessment dates
* Mean of 4 replicates, three assessment dates
( ) NIAB rating: 1 = susceptible, 9 = resistant

Table 6. Percent infection* of spring barley cultivars in *Rhynchosporium* isolation nurseries in 1993

Cultivar (NIAB rating)		WPBS naturally infected* (see text)	SCRI naturally infected[#] (see text)	RS-85-50* (BRV-1,2,3,4,5,6)
Chariot	(3)	58	18	10
Juno		55	15	24
Derkado	(3)	50	18	15
Cooper	(5)	50	14	12
Maris Mink		43	15	2
Alexis	(4)	39	12	16
Chad	(5)	38	9	15
Heron	(4)	38	11	1
Tyne	(5)	33	8	5
Nomad	(7)	31	10	5
Felicie	(7)	31	8	3
Goldie		30	14	9
Prisma	(6)	29	17	2
Delibes	(6)	26	14	2
Hart	(6)	24	11	2
Brewster	(7)	21	12	5
Blenheim	(7)	18	13	1
Camargue	(7)	13	10	0.1
Dandy	(7)	11	7	0.4
Proctor		11	7	0.1
La Mesita		10	2	3
Armelle		2		Trace
Digger		0.2	6	0.3
Osiris		0.1	3	0.0

* Mean of 4 replicates, final assessment dates
[#] Mean of 4 replicates, 3 assessment dates
( ) NIAB rating: 1 = susceptible, 9 = resistant



NET BLOTCH OF BARLEY

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Seedlings inoculated with isolates from the 1993 leaf samples of net blotch identified virulence factors compatible with only 3 of the differential cultivars. Frequencies of virulence to these cultivars has been at high levels in previous years. Additional winter and spring barley cultivars included in the tests displayed a range of responses to the 7 isolates.

GLASSHOUSE SEEDLING TESTS WITH 1992 ISOLATES

Nine samples of net blotch were received, all from winter barley cultivars (Table 1). Spore suspensions of *Pyrenophora teres* Drechs. prepared from 7 of the samples were inoculated onto seedlings of the 13 differential cultivars (Clifford, del Buono and Jones, 1984). Cultivar Marinka together with 17 additional winter and spring barleys from the NIAB Recommended List and Recommended List Trials were also included in the tests.

Results

Virulences compatible with the resistance factors in only 3 of the differential cultivars were identified (Table 1). Virulence to CI 9518 was carried by all the isolates. Two of the isolates induced a susceptible reaction type on Tenn.61-119. The only other differential variety susceptible to virulence factors carried by the 1993 isolates was Proctor. The frequency of virulence in the pathogen population to these 3 differential cultivars has been at a high level over a number of years (Jones and Clifford, 1993).

Table 1. Virulence combinations identified in 1993 isolates

Sample No.	Cultivar and location sampled		Virulence combination
BNS-93-2	Manitou	Cockle Park, Northumberland	11
BNS-93-4	Target	Cockle Park, Northumberland	11
BNS-93-5	Fakir	Cockle Park, Northumberland	11,12
BNS-93-6	Puffin	Bourn, Cambs.	9,11
BNS-93-7	Pipkin	Ely, Cambs.	9,11
BNS-93-8	Puffin	Dorset	9,11,12
BNS-93-9	Target	Halesworth, Suffolk	11

Only 1 isolate carried virulence compatible with cv. Marinka. The frequency of isolates carrying virulence to this cultivar has shown a decline in the pathogen population since it was first detected in 1987.

The winter and spring barley cultivars displayed a range of responses to the 1993 isolates. Cultivars Finch (W), Epic (W), Sprite (W), Heron and Delibes were susceptible to 5 or more of the isolates whereas cvs Gaelic (W), Swift (W), Juno and Brewster displayed lower levels of susceptibility with 2 or less isolates being compatible.

REFERENCES

Clifford, B.C., del Buono, R. and Jones, E.R.L. (1984). Net Blotch of Barley. U.K. United Kingdom Cereal Pathogen Virulence Survey Annual Report, pp.64-69.

Jones, E.R.L. and Clifford, B.C. (1993). Net Blotch of Barley. United Kingdom Cereal Pathogen Virulence Survey 1992 Annual Report, pp.47-49.

FUNGALLY-TRANSMITTED MOSAIC VIRUSES OF BARLEY

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Of 59 infected samples received in 1993, 56% contained barley yellow mosaic virus (BaYMV) and 54% barley mild mosaic virus (BaMMV). As in previous years, BaMMV was more frequent on malting cultivars (Halcyon, Pipkin, Puffin and Sprite) whereas BaYMV predominated amongst cultivars used for feed. One new "resistance-breaking" outbreak of BaYMV was reported bringing the UK total to 16.

INTRODUCTION

The survey, begun in 1987, aims to determine the distribution and relative frequency of the two mosaic viruses (barley mild mosaic virus: BaMMV; barley yellow mosaic virus: BaYMV) on winter barley, to detect regional or cultivar differences and to monitor the development of resistance-breaking strains. The diseases are soil-borne, being transmitted by the root infecting fungus *Polymyxa graminis*, and persist in soil for many years. A single (recessive) gene confers immunity to the common isolates of both viruses in a number of European cultivars but, since 1988, resistance-breaking isolates of BaYMV ("BaYMV-2") have been detected in the UK and other parts of Europe. Japanese experience also suggests that races of the virus with different specific virulences may be expected. New cultivars with resistance genes from East Asian barleys are being developed for the European market and a knowledge of the variation in these viruses and of their interaction with barley genotypes is therefore likely to become increasingly important especially in areas where winter barley is grown intensively and the diseases are most widespread.

METHODS

Plants with symptoms were received from MAFF CSL Harpenden Laboratory and also from farmers through a survey arranged by the Arable Research Centres. Leaves were tested by enzyme-linked immunosorbent assay (ELISA) for the presence of both viruses as described by Adams (1990).

RESULTS AND DISCUSSION

59 positive samples were received in 1993, far fewer than in the two preceding seasons. The proportions affected by the two viruses were very similar (56% with BaMMV; 54% with BaYMV). For the 48 samples of which the cultivar was known, BaMMV was again predominant on the malting cultivars (Halcyon, Pipkin, Puffin and Sprite). A small

Table 1. Mosaic virus samples from 1993, classified by cultivar

Cultivar	BaMMV alone	BaYMV alone	Both	Total Samples
Halcyon	2	0	0	2
Pipkin	3	1	0	4
Puffin	13	1	0	14
Sprite	0	0	1	1
Malting	18	2	1	21
Bronze	0	2	0	2
Fighter	3	1	0	4
Intro	0	1	0	1
Magie	1	0	0	1
Marinka	0	2	0	2
Pastoral	1	10	1	12
Plaisant	0	1	1	2
Posaune	0	1	0	1
Swift	0	0	1	1
Target (R)	0	1	0	1
Feeding	5	19	3	27
Unknown	4	5	2	11
Total	27	26	6	59

(R) = cultivar resistant to the common strain of BaYMV

number of samples contained both viruses and one new outbreak of "resistance-breaking" BaYMV was detected, bringing the UK total to 16 (Table 1).

In an attempt to examine variation within "resistance-breaking" BaYMV isolates, a set of Japanese differential cultivars were planted on several naturally-infested sites in 1992/3 in collaboration with NIAB. The cultivars developed rather few symptoms, perhaps because of rather late planting in the autumn and the mild winter. Only the cultivars susceptible to all Japanese strains routinely developed symptoms and the investigations are being continued for at least a further year.

REFERENCE

ADAMS M.J. (1990). The distribution of barley yellow mosaic virus (BaYMV) and barley mild mosaic virus (BaMMV) in UK winter barley samples, 1987-1990. *Plant Pathology* **40**, 53-58.

MILDEW OF OATS

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Race 5 (OMV 1,2,3) was identified from 80% of the 35 isolates. Virulence to the resistance derived from *Avena barbata* (OMV-4) was detected in the remaining 7 isolates.

SEEDLING TESTS WITH 1992 ISOLATES

Thirty-eight samples of *Erysiphe graminis avenae* were received in 1993 of which 25 were from spring oat cultivars and 13 from winter oats. Isolates were successfully cultured from 35 of the infected leaf samples and tested on a set of differential cultivars (Table 1).

Table 1. Differential cultivars used for isolate testing

OMR Group	Differential cultivar
0	Milford
1	Manod
2	Cc 4146
3	9065 Cn 6/3/74
4	Cc 6490

<u>Results</u>

Details of the mildew samples tested are given in Table 2. The frequency of occurrence of the various virulences detected in 1993 compared with previous years are given in Table 3.

Race 5 (OMV 1,2,3) was the predominant race with a frequency of 80%. The only other race identified from the 1993 isolates was race 7 (OMV 1,2,3,4) which is able to overcome the resistance carried by all of the differential cultivars. This race was found at a high frequency (73%) in 1991 but in 1993 as in the previous year, it was detected at a much reduced frequency in the pathogen population. Several of the isolates did give a type 2 reaction (moderate sized pustules with sporulation and some chlorosis and/or necrosis, but classified as resistant) on the differential cultivar Cc6490 (a translocation of *Avena barbata*).

Table 2. Locations and cultivars from which viable mildew samples were received in 1993 with virulences for each sample

Location	Cultivar	Virulence combination (OMV-)
ENGLAND (ADAS Region)		
<u>East Central</u>		
Headley Hall, North Yorkshire	Rhiannon (2)*, WW 17895(2), Aberglen, Melys	1,2,3
	Keeper, Melys, Aberglen, Dula	1,2,3,4
<u>East</u>		
Cambridge	Mirabel, Breeding Line	1,2,3
Suffolk	Image	1,2,3
Norfolk	Image	1,2,3,4
<u>South</u>		
Codford, Wiltshire	Dula	1,2,3
Bridgets, Hampshire	Dula	1,2,3
<u>West-central</u>		
Ross-on-Wye, Hereford	Craig, Gerald, Image, Kynon, 81/40CNS/1, Mirabel, Aintree, Pendragon	1,2,3
<u>North</u>		
Cockle Park, Northumberland	Dula	1,2,3
WALES		
Aberystwyth, Dyfed	Breeding Line	1,2,3
Trawsgoed, Dyfed	Keeper, Aberglen, Melys, WW17895	1,2,3
	Dula	1,2,3,4
SCOTLAND		
Aberdeen	Dula	1,2,3,4
	Winter Oat	1,2,3
Dundee	Keeper	1,2,3

* Value in parenthesis after cultivar name indicates number of samples received of that cultivar

Table 3. Virulence combination (race) frequencies identified from samples received in 1993 compared with previous years' races since 1983

Virulence Group	Race	Frequency (% total) 1983	1985	1987	1989	1991	1992	1993	No of isolates in 1993
OMV 1	2	15	0	0	0	0	0	0	0
1,2	3	77	37	15	0	3	0	0	0
1,3	4	0	0	0	0	0	0	0	0
1,2,3	5	8	46	85	85	19	83	80	28
1,2,4	6	0	4	0	0	5	0	0	0
1,2,3,4	7	7	13	0	15	73	17	20	7
No. of isolates tested		13	24	21	26	37	42	35	

CROWN RUST OF OATS

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Five virulence combinations were identified from the 1993 crown rust samples. Races 205 and 289 have been found at low frequencies in the pathogen population in recent years. Race 330 was last detected in 1971. A previously unidentified virulence combination, race 449, was carried by 1 sample. The commonly occurring race 251 was identified in the remainder.

Twenty-eight samples of oat crown rust were received from a range of winter (17) and spring (10) oat cultivars. One sample was of unknown origin. Isolates of *Puccinia coronata avenae* were cultured from 26 of the samples and tested on the International Set of differential cultivars. The majority of the samples came from three trial sites (Table 1).

Results

Five races were detected (Table 2) although some of the cultures appeared to comprise a mixture of races. The commonly occurring race 251 was identified in 21 samples. Race 205 which carries virulence to the differential cvs Anthony, Appler, Bond and Saia was identified in 2 isolates, CRS-93-11 and CRS-93-22, and race 289 identified in isolate CRS-93-26 have previously been identified in the pathogen population, albeit at low frequencies. An isolate cultured from a spring oat line at a trial site near Aberystwyth was identified as race 330 which was last detected in the U.K. in 1971. Isolate CRS-93-14 carried virulence compatible with the resistances of 6 of the differential cultivars and this race, 449, has not previously been identified in samples received by the UKCPV Survey.

Table 1. Locations and cultivars from which crown rust samples were received in 1993 with race identified for each sample

Location	Cultivar	Race
ENGLAND (ADAS Region)		
West-central		
Rosemaund, Hereford	Solva, Craig, Gerald, 81/40CNS/1, Image, Mirabel, Aintree, Pendragon	251
East		
NIAB, Cambridge	Pendragon, Mirabel, Aintree, Craig, Gerald, Chamois, Kynon, Image	251
		449
East Central		
Headley Hall, North Yorkshire	Unknown	251
South		
Bridgets, Hampshire	Dula	251
Codford, Wiltshire	Dula	205
WALES		
Trawsgoed, Dyfed	Dula, Valiant, Aberglen, Melys	251
	Keeper	205
	WW 17895	289
Morfa Mawr, Dyfed	Spring oat (breeding line)	330

Table 2. Virulence spectra of races identified from the 1993 survey together with virulence frequencies (%) corresponding to each differential cultivar

Differential variety	Race					Virulence frequency (%)
	205	289	330	449	251	
Anthony	S	R	R	S	R	12
Victoria	R	R	R	R	R	0
Appler	S	S	R	S	S	96
Bond	S	R	S	S	S	96
Landhafer	R	R	R	R	R	0
Santa Fé	R	R	R	S	R	4
Ukraine	R	R	S	S	R	8
Trispernia	R	R	R	R	R	0
Bondvic	R	R	R	R	R	0
Saia	S	S	S	S	S	100
No. of isolates	2	1	1	1	26	

R = resistant S = susceptible

VARIETY DIVERSIFICATION SCHEMES FOR WHEAT AND BARLEY, 1994

Variety diversification schemes to reduce the spread of mildew in spring barley and yellow rust in winter wheat have been produced by the UKCPVS Committee since 1975. In 1986, the barley scheme was expanded to include both winter and spring varieties. In 1988, spring wheat varieties were added to the wheat scheme. A scheme for brown rust of wheat was introduced in 1992. The schemes which follow update those in the last Annual Report.

The scheme for mildew of wheat was suspended in 1990, its usefulness having been severely restricted by the limited range of specific resistances in current varieties and the increasing complexity of the mildew population. However, the situation is under constant review and the mildew scheme will be reinstated when appropriate. Wheat varieties with good resistance to mildew are available and should be grown whenever possible.

Diversification 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-virulence on the other.

The general principles and history of the UK diversification schemes have 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 and Jenkins (1981).

REFERENCES

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September 1993

VARIETAL DIVERSIFICATION SCHEME TO REDUCE THE SPREAD OF MILDEW IN BARLEY 1994

Severe infection may result if mildew spreads between varieties which are susceptible to the same race of the pathogen. This risk is reduced if varieties with good resistance are grown. The spread of disease can be further limited by growing different varieties in neighbouring fields, provided that the varieties are not susceptible to the same races of mildew. The Diversification Scheme should be used to choose varieties to grow adjacent to one another.

Choosing varieties to grow together:

1. Select the first choice variety and locate its Diversification Group (DG).
   (S) = spring variety
2. Find this DG number under 'Chosen DG' down the left hand side of the table
3. Read across the table to find the risk of spread of mildew for each companion DG.
   + = Low risk of spread of mildew
   m = Moderate risk of spread of mildew
   M = High risk of spread of mildew
4. Wherever possible choose combinations of varieties marked '+'. A combination marked 'm' is a lesser risk than one marked 'M'.

DG 0
Bronze
Chestnut
Clarine
Finch
Frolic
Gaulois
Gypsy
Halcyon
Intro
Linnet
Marinka
Magie
Pastoral
Posaune
Puffin
Sprite
Swift
Target
Golden Promise (S)
Triumph (S)

DG 1
Fighter
Firefly
Willow
Alexis (S)
Atem (S)
Chariot (S
Dandy (S)
Derkado (S)
Felicie (S)
Forester (S)
Goldie (S)
Hart (S)
Heron (S)
Juno (S)

DG 4
Pipkin
Tyne (S)

DG 7
Brewster (S)
Chad (S)
Cooper (S)
Decor (S)
Delibes (S)

DG 8
Fakir
Manitou
Camargue (S)
Nomad (S)

DG 10
Epic
Gaelic
Kira
Torrent

DG 11
Blenheim (S)
Corniche (S)
Prisma (S)

September 1993

VARIETAL DIVERSIFICATION SCHEME TO REDUCE THE SPREAD OF MILDEW IN BARLEY 1994

Chosen DG	Companion DG 0	1	4	7	8	10	11
0	M	+	M	M	M	M	M
1	+	+	+	+	+	+	+
4	M	+	M	+	M	+	m
7	M	+	+	M	+	m	M
8	M	+	M	+	M	+	M
10	M	+	+	m	+	M	M
11	M	+	m	M	M	M	M

\+ = Low risk of spread of mildew

m = Moderate risk of spread of mildew

M = High risk of spread of mildew

Note: Varieties in DG 1 have good resistance to mildew spreading from any and can therefore be used to diversify with varieties in all DGs, including others in DG 1. Varieties in DG 0 are susceptible mildew spreading from any variety and therefore do not contribute to diversification.

September 1993

VARIETAL DIVERSIFICATION SCHEME TO REDUCE SPREAD OF YELLOW RUST IN WHEAT 1994

Severe infections may result if yellow rust spreads between varieties which are susceptible to the same races of the pathogen. 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. The Diversification Scheme should be used to choose varieties to grow adjacent to one another.

Choosing varieties to grow together

1) Select first-choice variety and locate its Diversification Group (DG). (S) = spring variety.
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
   Y= high risk of spread of yellow rust
   y = moderate risk of spread of yellow rust
4) Wherever possible choose combinations of varieties marked '+'. A combination marked 'y' is a lesser risk than one marked 'Y'.

DG1
Andante
Brigadier
Buster
Cadenza
Estica
Flame
Hunter
Hussar
Lynx
Mercia
Prophet
Torfrida
Zodiac
Promessa(S)
Tonic(S)

DG2
Admiral
Apollo
Beaver
Haven
Rialto
Slejpner

DG3
Riband

DG7
Hereward
Spark

DG8
Norman
Axona(S)
Baldus(S)

DG0
Genesis
Soissons
Alexandria(S)
Avans
Canon(S)
Rascal(S)
Sampan(S)

Chosen DG	Companion DG 1	2	3	7	8	0
1	+	+	+	+	+	+
2	+	**Y**	y	y	**Y**	**Y**
3	+	y	**Y**	y	**Y**	**Y**
7	+	y	y	**Y**	y	**Y**
8	+	Y	Y	y	Y	Y
0	+	**Y**	**Y**	**Y**	**Y**	**Y**

Note: Varieties in DG 1 have good resistance to yellow rust spreading from any variety and can therefore be used to diversify with varieties in all DGs, including others in DG 1. Varieties in DG 0 are susceptible to yellow rust spreading from any variety and therefore do not contribute to diversification.

April 1994

VARIETAL DIVERSIFICATION SCHEME
TO REDUCE SPREAD OF BROWN RUST IN WHEAT 1994

Severe infections may result if brown rust spreads between varieties which are susceptible to the same races of the pathogen. 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 brown rust. The Diversification Scheme should be used to choose varieties to grow adjacent to one another, and in consultation with the scheme for yellow rust.

Choosing varieties to grow together

1. Select first-choice variety and locate its Diversification Group (DG). (S) = spring variety.
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 brown rust
   - B = high risk of spread of brown rust
   - b = moderate risk of spread of brown rust
4. Wherever possible choose combinations of varieties marked "+". A combination marked "b" is a lesser risk than one marked "B".

DG1

Andante
Cadenza
Estica
Flame
Genesis
Lynx
Prophet
Torfrida
Avans (S)
Axona (S)
Baldus (S)
Promessa (S)
Sampan (S)

DG2

Hunter
Slejpner
Zodiac

DG4

Soissons

DG5

Buster
Canon (S)

DG0

Admiral
Apollo
Beaver
Haven
Norman
Rialto
Riband
Alexandria (S)
Rascal (S)
Tonic (S)

DG6

Brigadier
Hussar

DG7

Hereward
Spark

DG8

Mercia

DGU†

Avans (S)

† Unclassified resistances. Virulence detected in preliminary tests.

Companion DG

Chosen DG	1	2	4	5	6	7	8	0
1	+	+	+	+	+	+	+	+
2	+	B	b	b	b	b	b	B
4	+	b	B	b	b	b	b	B
5	+	b	b	B	b	b	b	B
6	+	b	b	b	B	+	b	B
7	+	b	b	b	+	B	b	B
8	+	b	b	b	b	b	B	B
0	+	B	B	B	B	B	B	B

<u>Note</u>: Varieties in DG1 have good resistance to brown rust spreading from any variety and can therefore be used to diversify with varieties in all DGs, including others in DG1. Varieties in DG0 are susceptible to brown rust spreading from any variety and therefore do not contribute to diversification.