REPORT 2000

Effectiveness of qualitative powdery mildew resistance in wheat and barley

and

Sensitivity of fungal cereal pathogens towards different compounds

from the research project:
Determining virulence patterns and sensitivity/resistance of airborne fungal pathogens of cereal for the successful use of disease resistances and for an efficient fungicide application.
for the 'Bundesländer' of the Federal Republic:

Rhineland-Palatinate (RP)	Hessen (HE)
Baden-Württemberg (BW)	Thuringia (TH)
Bavaria (BY)	Lower Saxony (NI)
Mecklenburg-Western Pomerania (MV)	

with financial support by the respective 'Bundesländer'.

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Annual reports on the current virulence situation and on the present status of resistance formation of the pathogens towards fungicides are available.
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INTRODUCTION

Airborne fungal pathogens, such as powdery mildews, rusts, *Septoria tritici* and barley net blotch represent important target pathogens for plant protection measures in crop cultivation. The **use of disease-resistant varieties** in concurrence with the **application of the most effective fungicides** are the basic pillars for reducing infestations within an integrated cultivation system that is striving to achieve sustainability. In addition, the legislator provides guidelines for land management, in order to ensure the protection of both the environment and humans. Integrated plant protection has clearly been adopted as basic principle for all protection measures.

The high adaptation potential of the pathogen poses a large problem for appropriate control measures. The wind-dispersal of the pathogen causes additional problems, as adapted pathotypes can rapidly spread over vast areas. A high degree of alertness and flexibility is therefore necessary in order to control the pathogen with effective protection measures.

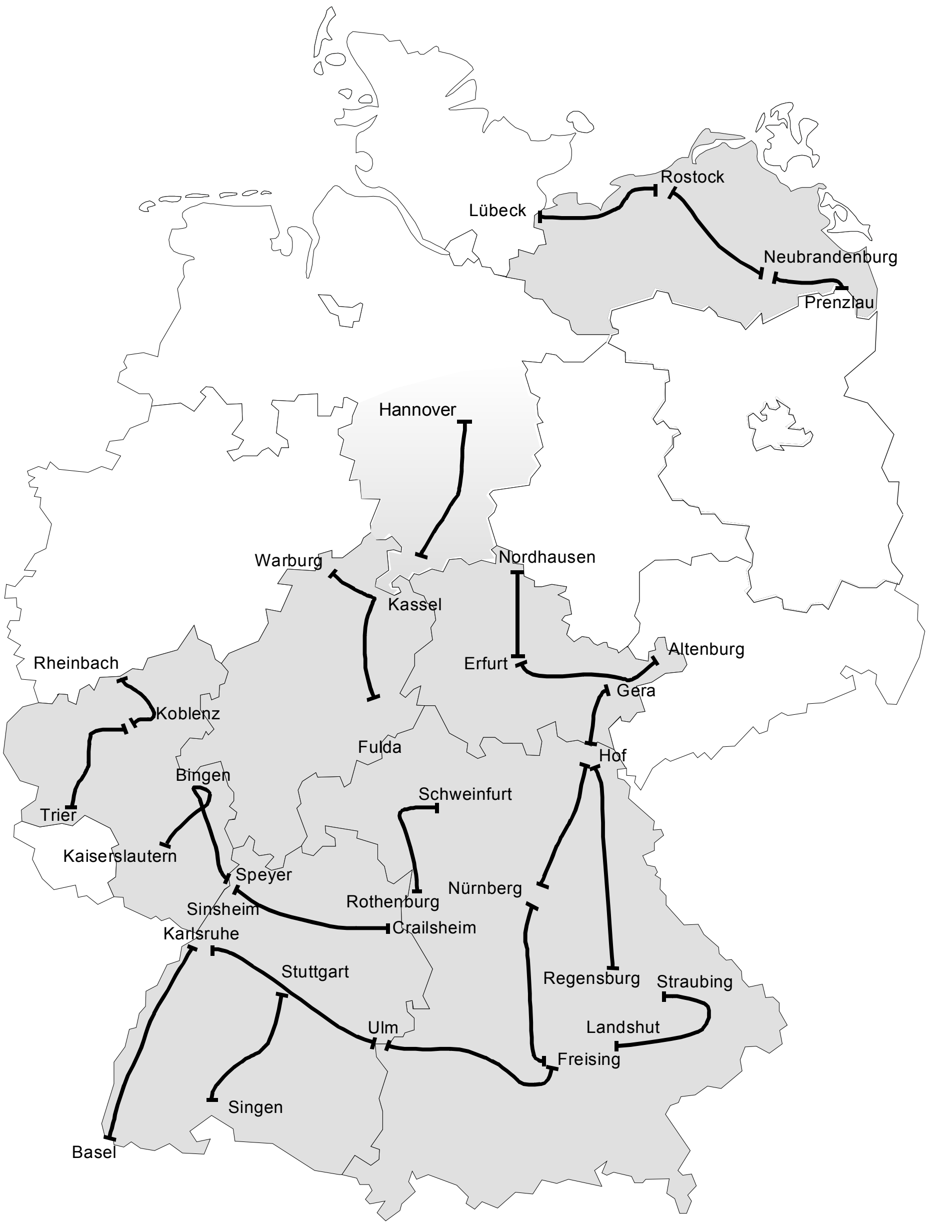
An efficient use of the different resistance genes and gene combinations of the available cereal assortment and the application of effective fungicides requires sufficient knowledge about the appropriate characteristics of pathogen virulence and sensitivity. Location-specific information is also necessary due to differing regional conditions. The task of the studies is therefore to develop a database, which demonstrates the current status of pathogen adaptation, for the use in advisory services and resistance breeding. In addition, the dynamics of pathogen adaptation becomes evident with increasing data over a wider time range, thus enabling a forecast for future years.

The study is divided into two parts:

- **a virulence analysis of wheat and barley powdery mildew, and**
- **an investigation into the fungicide sensitivity of significant cereal pathogens.**

The regional populations of the respective pathogen are examined annually by mounting a jet spore trap on the roof of a vehicle. Representative samples of pathogen spores are caught directly from the air when driving past the various cultivation areas. Figure 1 shows the route selection for the 2000 analyses. Field samples are only taken in the case of *Septoria tritici*. The pathogens are then tested for their virulence and fungicide sensitivity under laboratory conditions. Progeny of the trapped spores are primarily examined on test assortments comprised of leaf segments. This research method ensures the safe analysis of high numbers of pathogen isolates.

Fig.1: Routeselection for the sample of 2000 in the 'Bundesländer' of Mecklenburg-Western Pomerania, Lower Saxony, Thuringia , Hessen, Rhineland-Palatinate, Baden-Wuerttemberg and Bavaria



THE CURRENT STATE OF VIRULENCE

Background

Throughout this report, the current state of virulence of both wheat and barley powdery mildew will be shown in comparison with the vertical/qualitative resistance genes of the varieties. The advice of the Federal Biological Research Station in Kleinmachnow (Dr. K. Flath) for the selection of the examined resistance characteristics was followed.

If a pathogen isolate possesses the virulence towards the respective host resistance, it can still grow and propagate on a variety containing the specific resistance. The regional occurrence of virulence within the pathogen population serves as benchmark for the evaluation of the effectiveness of the resistance compared to the respective resistance gene. It thus indicates the proportions of barley and wheat powdery mildew that contain virulence against the particular resistance. The higher the proportion or the frequency of virulent isolates in the pathogen population, the less actual effect will be exerted by the specific resistance gene. **The efficiency of the resistance genes of the different varieties can therefore be directly determined on the basis of the established values (virulence frequency).** The "Beschreibende Sortenliste 2000 für Getreide, Mais, Ölfrüchte, Leguminosen und Hackfrüchte" (published by: Bundessortenamt; Verlag Landbuch Verlagsgesellschaft mbH, Hannover; E-mail: buch@landbuch.de; Internet: http://www.landbuch.de; wheat powdery mildew: pp. 75-78; barley powdery mildew: pp. 84-87) provides information on the distribution of resistance genes in released varieties. A few new varieties that are listed in the above list have been designated as „U" = „unknown", this could be due to very distinct resistance genes or gene combinations.

According to the available information a virulence frequency of
0 - 10 % offers a very good to good (+++)
10 - 20 % barely offers a good (++), an even more reduced under high infection pressure
20 - 50 % offers a moderate, however still apparent (+)
> 50 % offers a small and hardly noticeable (0)
protection against powdery mildew.

Apart from the vertical/qualitative (= pathotype- / race-specific) resistances the individual varieties often possess additional horizontal/quantitative (= pathotype- / race-nonspecific) resistance characteristics. These are, however, very difficult to analyse and are not the subject of these investigations. But, they can possibly lead, under certain circumstances, to the situation in which varieties with the same qualitative resistance characteristics receive different evaluations of infestation in the field. The real resistance effect of the qualitative resistance genes can therefore be masked by quantitative defence mechanisms. This has especially been noticed with wheat varieties.

1. Virulence of Wheat Powdery Mildew

Tab. 1: Practice-relevant estimation of the effectiveness (ranging from ‘0’ to ‘+++’) of qualitative resistance genes towards wheat powdery mildew in the varieties released in 2000.

Resistance gene	Effectiveness	Regional differences	Comments
Pm1	+	low	
Pm2	0	no	
Pm3c	+	low	
Pm3d	++	low	Youth resistance
Pm4b	0	no	
Pm5	+	no	Adult resistance
Pm6	+	no	Adult resistance
Pm8	0/(+)	low	
Pm9	+/++	low	
MlAx in ‚Cadenza’	+++	low	
U in ‚Troll’	+++	no	
U in ‚Cordez’	+++	low	
Pm5+Pm6	++/+++	low	Synergy effects

Towards Pm1:
The virulence frequency does not exhibit a pronounced regional differentiation in Southern Germany and mostly lies within the range of 20 - 50 %. The protective effect of Pm1 can therefore only be classified as moderate. Pm1 presently occurs exclusively in some areas of summer wheat cultivation, where it can still contribute to successful powdery mildew protection. It is only used in combination with other resistance genes.

Towards Pm2:
Pm2, for several years now, no longer achieves efficient protection in RP, BW and BY; the virulence frequency has almost reached the 100 % - level. In cases were pure Pm2 varieties, for example the variety “Tower”, offer a fairly good protection against powdery mildew, this protection stems almost exclusively from its relatively high level of horizontal/quantitative (thus pathotype independent) powdery mildew resistance (see ‘Background’). As it is more difficult for the pathogen to overcome this type of resistance, a medium- to long-term continuation of the powdery mildew protection can be expected.

Table 2: Virulence of wheat powdery mildew in samples from different regions of Rhineland-Palatinate, Baden-Wuerttemberg and Bavaria, 2000

Region	n	Pm1	Pm2	Pm3c	Pm3d	Pm4b	Pm8	Pm1+2+9	Cortez	Troll	MlAx
Rhineland-Palatinate:											
Rheinbach-Koblenz	10	20	100	50	0	80	70	0	0	0	0
Koblenz-Trier	18	39	94	33		100	39	17	0	0	6
Speyer-Bingen	49	51	100	45	8	100	67	12	0	0	4
Baden-Wuerttemberg:											
Sinsheim-Crailsheim	50	22	100	52		100	84	8	0	0	0
Karlsruhe-Basel	11	73	82	36		100	64	0	0	0	0
Karlsruhe-Ulm	43	40	98	56	0	95	63	9	0	0	0
Stuttgart-Singen	11	36	91	64		100	73	36	0	0	0
Bavaria											
Schweinfurt-Rothenburg	20	50	95	35	5	90	90	5	0	0	0
Hof-Nürnberg	16	25	94	44	0	75	88	6	0	0	0
Hof-Regensburg	8	50	100	50	0	100	75	0	0	0	0
Nürnberg-Freising	30	47	93	27	4	80	87	0	0	0	0
Ulm-Freising	35	31	94	26	6	100	89	0	0	0	3
Niederbayern	38	26	100	37	3	97	97	8	0	0	0

Towards Pm3c:

The resistance gene Pm3c offers only a moderate protection in Southern Germany. The virulence frequencies increased before 1998 and are since oscillating between 30 % and 60 %. A clear regional differentiation, as predominant a few years ago, is hardly detectable anymore. Only the variety "Borenos", which enjoyed high popularity in the first half of the 90's, contained the resistance. However, no currently released variety possesses this resistance.

Towards Pm3d (previously ‚Mlk'):

A relatively low virulence frequency towards this resistance, exclusively used for some areas of summer wheat cultivation, is present in Southern Germany, indicating a fairly good effectiveness. The proportion of Pm3d-virulent isolates in the regional samples is still below 10 %. For a correct estimation of Pm3d, however, one must consider that the resistance is probably only fully expressed in the early development stages of the plants. Only limited success can therefore be expected with increasing plant age, despite the relatively low virulence frequency.

Towards Pm4b:

Following a dynamic adaptation process of the fungus over the last 15 years, caused by a permanent and relatively high selection pressure, the proportion of virulence to Pm4b in the pathogen populations generally lies between approximately 80 % and 100 %. Pm4b therefore no longer offers an effective mildew control.

Towards Pm5:

Pm5 can probably only unfold its full resistance effect in later development stages of wheat. The virulence analysis, which examines the disease development on young plants (first leaf), can therefore only inadequately determine the actual virulence frequency. However, our studies indicate an increasing virulence development. It remains to remark that Pm5 still shows a certain protective effect, in particular in combination with Pm6, which also expresses its resistance in later stages of plant development (see next paragraph). Especially this combination seems to unleash a complementary and intensifying defence reaction, which seems to be difficult to overcome by the pathogen. A relatively good quantitative resistance background may also be dominant in some Pm5+Pm6 varieties, in particular with Pm5 varieties showing very good scoring values in field conditions.

Towards Pm6:

The Pm6 resistance also expresses its full resistance effect with increasing plant age. Similar to Pm5, this causes a deceleration of the dynamic fungal adaptation process, yet not its prevention. An accurate determination of the Pm6-virulence frequency is again difficult. Based on the results of the analysis, one can determine an obvious increase in the virulence frequencies to levels of more than 50 % within the past years. This suggests a low protection against powdery mildew by Pm6 alone. Appropriate varieties with very good scoring values in field conditions, for example "Clever", "Kris", (both Pm2+Pm6) or "Drifter" (Pm2+Pm4b+Pm6), possess a more effective quantitative resistance base which is not as pronounced in the variety "Ritmo". Moreover, apparent synergies arise, particularly when combining the two adult plant resistances Pm5+Pm6 (see above).

Towards Pm8:

Already in the 80's a high level of Pm8-virulence was established with values of up to 100 %. The basic situation has since not changed much. However, a certain decrease of virulence frequencies in BW and RP has been noticeable for a few years now. But the values in those areas still remain generally over 50 %. Similar to the resistance genes Pm2 and Pm4b, Pm8 does not offer any considerable disease protection. Even the combination of three genes does not bring a satisfying success (e.g. Pm2+Pm4b+Pm8 in variety "Apollo" which was very popular ten years ago), since the majority of powdery mildew isolates possess the virulence combinations suitable for all three resistance genes. It is also necessary to say that whenever an appropriate variety such as "Tarso" (only Pm8) demonstrates a good protection against powdery mildew, this is - almost exclusively - based on quantitative resistance characteristics.

Towards Pm9 with the gene combination Pm1+Pm2+Pm9:

Since Pm9 is not exclusively present in any variety and thus cannot be tested in isolation, virulence analyses for the gene combination Pm1+Pm2+Pm9 were undertaken in 2000 to estimate the effectiveness of Pm9. The virulence frequencies towards Pm1+Pm2+Pm9 decreased on a regional scale, compared to previous years, in some cases noticeably. The values generally merely oscillated between approximately 0 % and 20 % in 2000, levels only exceeded 20 % in the region between Stuttgart and Singen. When considering the results of the resistance genes Pm1 and Pm2, a virulence frequency between 20 % and 50 % is suggested, so that only a fairly reduced protection against powdery mildew is exerted by Pm9 alone.

Towards U in "Cordez":

No isolate virulent to the resistance U in "Cordez" could be found in 2000. The resistance will therefore provide very good protection during the 2001 growing season.

Towards U in "Troll":

Again, no powdery mildew isolate with suitable virulence to the resistance U in the summer wheat variety "Troll" could be found in 2000. The U-resistance in "Troll" is therefore still highly effective, the variety "Troll" is, however, not listed in the variety list of 2000.

Towards MlAx in "Cadenza":

The virulence frequencies are still low, and varied between 0 % and approximately 5 % in 2000 as in the previous year. A fairly good protection against powdery mildew can generally be expected. However, no variety with this resistance is currently released.

The genetic qualitative resistance base against wheat powdery mildew only experienced little extension until 1997, in the sense of developing new resistance genes. The results show that the "established" genes mostly offer only little satisfying protection. An increase of the genetic base of the qualitative powdery mildew resistance was therefore a primary target for breeding efforts. The breeders have come closer to attaining this target, since the varieties now show new resistance characteristics. However, a more precise identification of the resistance characteristics designated “U” has so far not been possible, indicating that they could be the result of several distinct genes or gene combinations.

Besides, a comparison of the data with scores from field experiments shows that a considerable base of quantitative resistance is present in a number of predominantly newer varieties. This base, by itself, already ensures a very good protection against powdery mildew, whereas the main resistance (qualitative resistance gene/-combination) only partially contributes to the protective mechanism. Substantial successes were therefore achieved in the last few years in the field of quantitative resistance breeding against wheat powdery mildew.

2. Virulence of Barley Powdery Mildew

In addition to the Bundesländer mentioned previously, the Bundesland of Thuringia was also included in the investigations for barley powdery mildew virulence.

Table 3: Practice-relevant estimation of the effectiveness (ranging from '0' to '+++') of qualitative resistance genes towards barley powdery mildew in the varieties released in 2000.

Resistance gene	Effectiveness	Regional differences	Comments
Mla1	++	low	presently no variety
Mla3	+/++	present	
Mla6	0	no	
Mla7	0	no	
Mla9	+	low	presently no variety
Mla12	0/+	low	
Mla13	+/++/++	present	
MlLa	0/+	present	
Mlg	0	no	
Ml(St)	0/(+)	no	
Ml(Si-1)	+++	no	
U (We) in ‚Scarlett'	0	no	
U in 'Meltan'	++/+++	low	
mlo	+++	no	very permanent

Towards Mla1 (Al):
Since this resistance gene does not presently occur in any released variety (last variety with Mla1: 'City') and no selection pressure is acting on the barley powdery mildew population, the virulence analysis for Mla1 was discontinued in 2000 in order to include other resistance genes/lines. The values in South Germany varied between < 5 % and 20 % in 1998, which represented a good to very good protection against powdery mildew.

Towards Mla3 (Ri):
The virulence situation towards the resistance gene Mla3, which is currently only present in the variety 'Tilia', remains largely stable around the attained levels. An identifiable regional differentiation is still prevalent. Values of ≤ 20 % are found in TH, RP, BY, Lower Franconia, Swabia, Lower Bavaria and in most regions of BW. Values between 30 % and 40 %, however, prevail in the northeast of BY. Thus only a reduced protection is available against powdery mildew.

Table 4: Virulence of barley powdery mildew in samples from different regions of Thuringia, Rhineland-Palatinate, Baden-Wuerttemberg and Bavaria, 2000

Region	n	Mla3	Mla9	Mla 13	MlLa	St	Scarlett	Baccara	Meltan	Mlo
Thüringen:										
Nordhausen-Erfurt	50	10	46	64	30	92	90	0	0	0
Erfurt-Gera-Altenburg	32	22	22	38	66	41	44	0	0	0
Rheinland-Pfalz:										
Rheinbach-Koblenz	18	22	44	44	28	83	83	0	0	0
Koblenz-Trier	23	22	52	43	22	70	83	0	4	0
Speyer-Bingen	21	10	19	24	24	100	95	0	0	0
Baden-Württemberg:										
Sinsheim-Crailsheim	11	0	33	8	25	67	83	0	0	0
Karlsruhe-Basel	10	30	50	20	80	60	80	0	0	0
Karlsruhe-Ulm	50	16	32	26	22	98	96	0	0	0
Stuttgart-Singen	11	6	39	22	44	94	100	0	0	0
Bayern:										
Schweinfurt-Rothenburg	8	0	50	50	25	100	100	0	0	0
Hof-Nürnberg	45	29	20	27	20	87	78	0	0	0
Hof-Regensburg	48	38	33	21	60	98	65	0	0	0
Nürnberg-Freising	39	36	15	8	41	74	59	0	0	0
Ulm-Freising	9	0	22	22	89	100	100	0	0	0
Niederbayern	12	8	33	0	25	67	58	0	0	0

Towards Mla6 (Sp: here in combination with Mla14):
High frequencies of virulence (up to 100 %) towards Mla6 are the result of a long lasting, intensive selection process in numerous winter and summer barley varieties. In the investigations of 1999 a very high proportion of barley powdery mildew isolates possessed an appropriate virulence throughout South Germany. The virulence frequencies varied, as in the previous years, between approximately 70 % and 100 %. Therefore, most of the appropriate regional-specific collections were omitted in 2000, and the analyses of the few conducted showed that only a barely noticeable protection can still be expected against powdery mildew.

Towards Mla7 (Lv: here in combination with Mlk):
The virulence frequencies towards the resistance gene Mla7 increased in South Germany over the last years. A high level of virulence of mostly 80 % to 100 % was already present in 1999 and caused again by preceding high selection pressure for both winter and summer barley varieties. Since Mla7 hardly offers any protection, the analyses were discontinued in 2000.

Towards Mla9 (Mc: here in combination with Mlk):
No variety with this resistance is presently released according to the “Beschreibende Sortenliste 2000 für Getreide, Mais, Ölfrüchte, Leguminosen und Hackfrüchte“. But powdery mildew nevertheless frequently contains the appropriate virulence due to the virulence selection of previous years for Mla9. The 2000 results generally demonstrate virulence frequencies from approximately 20 % to 50 %. This resistance would therefore only produce a reduced, moderate protection in South Germany against powdery mildew should a new variety containing the Mla9 resistance be introduced onto the market.

Towards Mla12 (AR):
The virulence frequencies towards Mla12 were mostly below 50 %. The continuous selection pressure, which lasted a few years on winter, primarily, however, on some popular summer barley varieties, was the cause for the decrease of resistance effectiveness. Mla12 therefore only possesses a moderate to very small effectiveness. A virulence analysis was not necessary in 2000, since no serious modifications were to be expected.

Towards Mla13 (Ru):
Regional differences in the virulence frequencies towards Mla13 are visible, although most values are situated around the 20/30 %-mark. The highest value in 2000 was obtained in the northern TH. In BY the highest value was similar to the previous year in Lower Franconia, the lowest in South Bavaria.

Towards MlLa (La):
Although a serious increase of virulence, regionally up to 100 %, was detectable in the past, the virulence situation towards MlLa has recently improved. A decrease of the virulence frequencies is noticeable in recent times, and the virulence level has again regionally reached values of below 50 %. Within the spectrum of released varieties, the resistance is currently only present in the winter barley ‚Jana’, which is only being cultivated in a small area.

Towards Mlg (We [previously CP]):

Due to longlasting experience in virulence towards the Mlg resistance an analysis can be omitted in order to include other, more interesting, resistance characteristics. The Mlg resistance has been used for several decades, so that a high proportion of the barley powdery mildew showed the appropriate virulence as early as the 60's. High levels of virulence frequencies of over 50 % without an identifiable regional differentiation were also detected in the previous years. A similarly high level can currently be expected. No effective powdery mildew protection can therefore be anticipated from the Mlg resistance alone.

Towards Ml(St) (St):

The virulence towards Ml(St) continued to rise, whereby high virulence frequencies prevail with values between 60 % and 100 %. No satisfactory powdery mildew protection can be expected of Ml(St), which was crossed into both winter and summer barley varieties. Varieties such as 'Vanessa', which - according to the "Beschreibende Sortenliste 2000 für Getreide, Mais, Ölfrüchte, Leguminosen und Hackfrüchte" - receive a fairly good scoring value, probably receive their powdery mildew protection primarily from an above-average quantitative resistance characteristic (see 'Background').

Towards Ml(Si-1) (Si-1):

No virulence towards the resistance in Ml(Si-1) could be detected in any of the barley powdery mildew samples from South Germany in 2000. The virulence frequencies in the samples were therefore at 0 %, even in the Karlsruhe-Ulm region, where a virulent isolate was found in 1999. The resistance from Ml(Si-1) is therefore classified everywhere as ‚very good'.

Towards U (We) in'Scarlett':

The regional virulence frequencies towards the resistance characteristics of the popular variety ‚Scarlett' have risen extremely strongly in the entire investigation area of South Germany, whereas hardly any regional differences can be detected. The values generally vary between 60 % and 100 %, hardly any protective effect emanates from this powdery mildew resistance.

Towards U in 'Meltan':

The virulence frequencies towards U in 'Meltan' were still relatively small in 2000 and generally had values of 0 %. The only Meltan-virulent isolate was found in the sample from the Trier-Koblenz region. The powdery mildew protection emanating from the resistance characteristic in 'Meltan' is therefore classified as still relatively good.

Towards mlo (Mlo):

Background: The Mlo resistance of all - so far in Germany released - Mlo varieties can probably be attributed to two sources. One source is comprised of three races from Ethopia (‚L92', ‚L100', ‚Grannenlose Zwei-zeilige'), which all presumably contain the Mlo11 gene. The second source is a mutant (‚Diamant Muntante') with the gene allocation Mlo9 and which was developed in the 40's.

Whenever working with the Mlo resistance, one has to consider the special position of Mlo within the

qualitative resistance genes. Current knowledge states that the gene releases a multilevel defence mechanism within the metabolic system of the plant. The sufficient formation of papilla in the infection locus plays a central role in the resistance mechanism. In cases when the isolate is ‘avirulent’, the elongated cells of the leaf epidermis react fully resistant, the short epidermis cells surrounding the stomata openings react, however, only moderately resistant (intermediate), and the stomata cells are even fully susceptible. Due to the complex defence mechanism, a successful adaptation of the pathogen can probably not be achieved via the modification of one single gene, but only by the mutation of several genes. The Mlo virulence does thereafter not follow the classic ‘gene-for-gene hypothesis’, but can probably be achieved only gradually, rather quantitative and with substantial temporal delay.
The present situation: Only when including the above considerations, it becomes comprehensible that **no** Mlo virulent isolate could be found for the 2000 analysis in South Germany. Despite a long-lasting and massive selection pressure, the pathogen has not yet managed to successfully adapt to the Mlo-resistance in the field (to detectable levels). The virulence frequencies are everywhere at 0 %, which displays a continuing excellent protection by Mlo against barley powdery mildew.
However, many years ago, a relatively simple selection experiment without any mutagenic compounds has shown that the pathogen possesses a basic potential for adaptation to this resistance characteristic. Adapted pathotypes have repeatedly been reported for experiments in greenhouse conditions. So far, the pathogen has not yet managed to successfully reproduce and multiply such an isolate in the field.
So far, only isolates could be found, which are categorised as ‘faintly virulent’ or ‘intermediate virulent’ (success of infection of ≤ 50 % relative to the highly susceptible control variety) and which show strong variations in infection success under several test repetitions. These observations can be explained with the more complex mechanism of Mlo resistance.
Moreover, the results indicate the existence of an unusually strong **environmental dependency during the expression of the Mlo resistance**. The powdery mildew seems to be capable of successfully infecting stressed plants with partial expression of the Mlo-resistance. Investigations showed that the water regime of the plant plays a crucial role. It was proven that Mlo-containing barley plants suffering under water stress were clearly increasingly susceptible to powdery mildews. At the same time, one has to emphasise that only certain, apparently quantitatively adapted isolates, which had shown increased aggressiveness in laboratory conditions, managed to successfully infect in the above experiments. This could lead to a restriction of the resistance development, e.g., during high water requirement in the elongation phase of the plants (GS 30-39) in dryness or preceding water stress. It appeared during the experiments that strong differences existed between varieties. The variety ‘Krona’ for instance had an especially sensitive reaction to water stress. False estimates of Mlo varieties under certain climatic/soil conditions or at certain growth stages are therefore possible. A sometimes observed increased infection of powdery mildew of Mlo varieties especially during the elongation phase can thus be attributed to the above explanation.

THE CURRENT SITUATION OF FUNGICIDE SENSITIVITY

The investigations for the analysis of fungicide sensitivity were expanded to a substantial extent in 2000. On the one hand further regions and Bundesländer, besides RP, BW and BY, were included in the study (see Fig. 1). On the other hand, the pathogen range was considerably increased, mainly due to the need for information regarding a possible adaptation or resistance formation of cereal pathogens towards the strobilurin compounds. Analyses of sensitivity of the following pathogens were therefore undertaken:

- wheat powdery mildew
- barley powdery mildew
- brown rust of wheat
- brown rust of rye
- *Septoria tritici*
- net blotch of barley

Background

One has to differentiate between two versions of the adaptation of sensitivity or resistance selection of fungal pathogens towards compounds with fungicidal effect:

1. On the one hand there is the so-called disruptive / qualitative resistance formation ('single-step resistance') as represented in Fig. 2 below. In this case, the compound is no longer effective or its efficacy is extremely reduced, as the pathogen achieves a highly reduced sensitivity with only one genetic modification. The compound is hardly effective in the field, if a large part (high percentage) of the pathogen population has acquired this characteristic. One can fall back on the experiences with the development of virulence of wheat and barley powdery mildew towards the qualitative resistance genes of the host plants (see above) for a relevant evaluation of the measured data for the practice.

With a frequency of resistant isolates in the regional population of

0 - 10 % a very good to good,

10 - 20 % barely a good, in case of high infection pressure an even more reduced

20 - 50 % a moderate, however still noticeable, and

> 50 % a small and hardly noticeable

protection against powdery mildew is to be expected.

A very recent example is the initial observation of resistance formation of wheat powdery mildew towards strobilurin derivatives in 1998.

2. The so-called continuous / quantitative sensitivity adaptation ('multi-/oligo-step resistance') acts in a completely different way. This type, which is often described as 'shifting', is the typical adaptation reaction of the pathogens to the compounds of the SBI group (Sterol biosynthesis inhibitors: triazols, morpholines, piperidines, spiroketalamines). The pathogens can thereby only adapt gradually by accumulating several genetic modifications, as shown in Fig. 2. First adaptation reactions often remain unnoticed, since these are generally not visible in the field. A reduction in sensitivity, detected via appropriate analyses, does therefore not immediately mean a noticeable loss of effectiveness of the respective compound in field conditions. It rather represents a measurable reduction in sensitivity of the pathogen in relation to the originally available sensitivity (wild-type sensitivity), which primarily attacks the reserves of the compounds and is associated with a gradual reduction/shortening of the fungicide's effect. An increasing diversity of differing sensitive or adapted isolates within the total population during the progressive resistance formation is characteristic for this form of adaptation.

One has to consider that the actual effect of the compounds in the field depends on various factors. The quantitative adaptation of the pathogen mostly becomes a dominant factor only with advanced reduction in sensitivity. Further factors are the effective reserve, given by the manufacturer via the dosage recommendation, the rate and extent of the compound uptake in the plant, as well as its transport and distribution in or on the plant including its stability in or at the plant fabric. The climatic conditions during and after the application are likewise of importance. Triazole derivatives develop their full performance potential mostly in warm and dry weather, while a morpholin has its optimal performance in humid and somewhat cooler conditions. The quantitative sensitivity adaptation is more difficult to describe and the data cannot be transferred into practice as easily as for the qualitative adaptation. **The relation between the current sensitivity level of the examined population and the original sensitivity level is essential. The medium resistance factor MRF of the pathogen population can be derived from this relationship.**

$$\text{MRF} = \frac{\text{Current sensitivity of the examined population towards the compound}}{\text{Unselected initial level ('wild-type' sensitivity)}}$$

The fact that one cannot generalise the evaluation of the MRF values presents a difficulty, i.e. a MRF of 10 towards the compound X must not necessarily have the same effect as with the compound Y. A specific evaluation is therefore necessary for each compound.

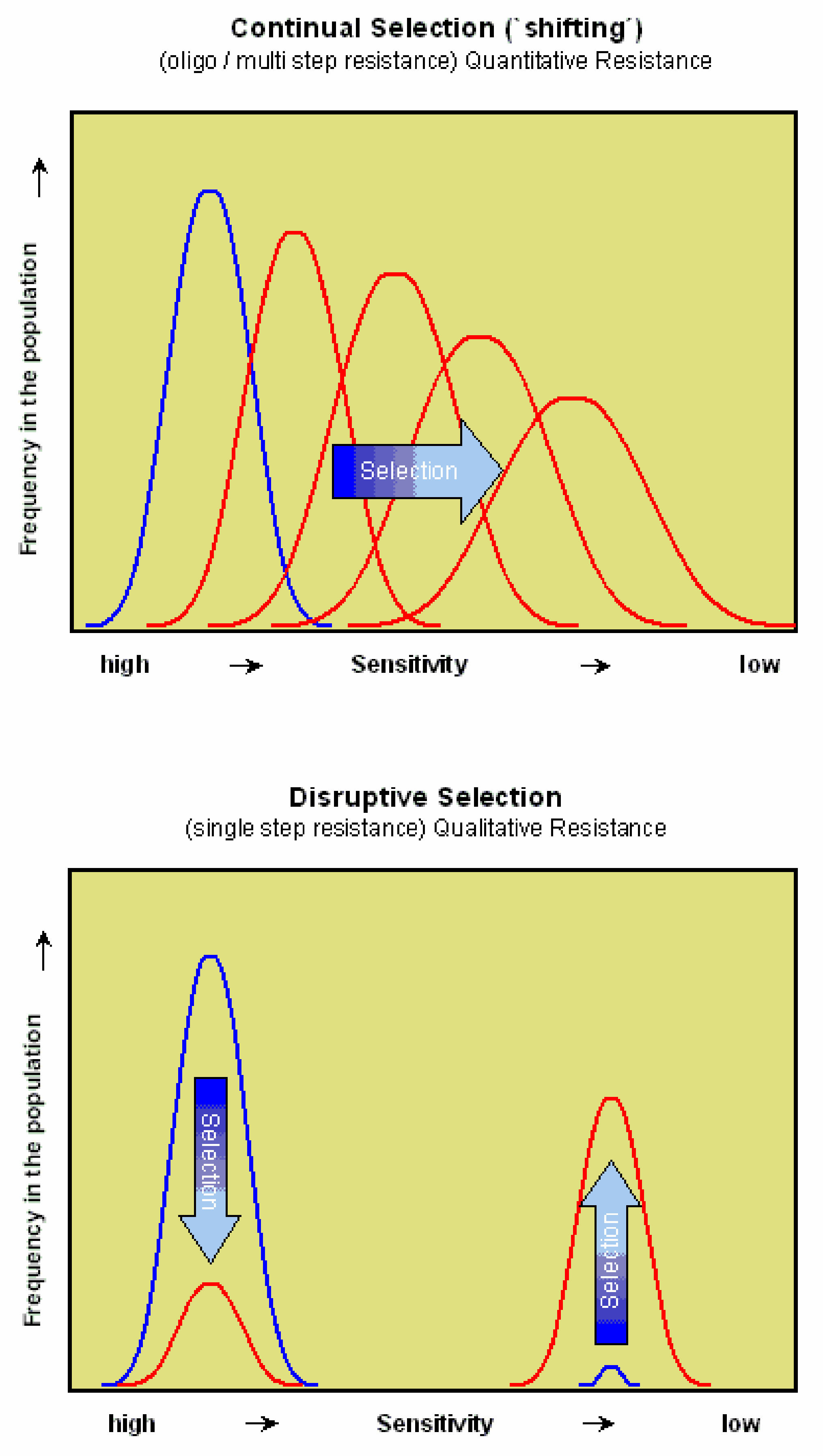


Fig. 2: Schematised diagram of the population dynamics with a reduction in sensitivity of the pathogen population by continuous or disruptive selection: Blue curves: Original sensitivity distribution; red curves: Sensitivity distribution according to selection by application of fungicides

Important:

In order to facilitate the understanding and the implementation of the results presented in the available situation report, the simplified characterisation of the adaptation or the resistance formation (with values between 0 and 10) will be added to the description of the sensitivity situation. An estimate is thus being made that directly enables a comparison between the different compounds. The evaluation occurs by including all the information available to us. The evaluation code was modified in order to place all compounds into a common scale and differs in some parts substantially from that of previous years (until 1998), which was exclusively harmonised towards the quantitative adaptation of the pathogens.

The evaluation code is set up as follows:

0: no measurable signs of resistance formation.

3: barely a good or obvious success can be expected despite a measurable adaptation reaction; however, particularly the duration and/or - during qualitative resistance formation - the security can already be impaired.

4: a clear loss in efficiency has to be expected under favourable climatic conditions, with advanced infestation of the stock or high infection pressure.

5: visible or clearly measurable restriction of protection success, in particular with reduced quantities of the respective compound.

8: clear (for quantitative adaptation, see above) to drastic (for qualitative adaptation, see above) loss of effectiveness in field conditions, even with the full quantity of the sole compound.

10: no or just a marginal difference between treated and untreated tests.

1. Compound sensitivity of wheat powdery mildew

The investigations of the last few years have shown that the wheat powdery mildew populations have reached a distinct stabilisation in the adaptation levels of their sensitivity towards the compound of the Triazole group. The emphasis during the analyses of 2000 was set on the new classes of strobilurins, chinolines and anilinopyrimidines, besides morpholin-like compounds.

Table 5: Practice-relevant estimation of the sensitivity situation of wheat powdery mildew for the study area, 2000.
Evaluation code 0 to 10 (see above):
0: no signs of resistance formation → no loss in effectiveness
10: max. advanced sensitivity loss → full loss of efficiency

Compound	Solo-product	Evaluation of adaptation/resistance formation	
Triazoles:			
Triadimenole	Bayfidan	6	
Propiconazole	Desmel	5	
Tebuconazole	Folicur	4	
Cyproconazole	Alto 100	3/4	
Epoxiconazole	Opus, (Opus top)*	4/5	
Morpholines / Piperidines / Spiroketalamines:			
Fenpropimorph	Corbel	3/4	
Fenpropidin	Zenit M	3	
Spiroxamine	Impulse	3	
Strobilurins:			
Kresoxim-methyl	(Juwel top)*	2 – 10	high regional differences
Azoxystrobin	Amistar	2 – 10	high regional differences
Trifloxystrobin	(Stratego)*	2 – 10	high regional differences
Chinolines:			
Quinoxyfen	(Fortress top)*	0	
Anilinopyrimidines:			
Cyprodinil	Unix	0	

*only available in combination with other compounds

A) Triazoles (DMIs: Demethylation Inhibitors)

Triadimenol (or its forerunner triadimefon, which is converted into the more active triadimenole in the plant) has been used since the end of the 70's and propiconazole since the beginning of the 80's. Their extensive and intensive application led to a noticeable sensitivity adaptation of the wheat powdery mildew populations in the 80's in form of a gradual selection and, in some cases, also led to an apparent decrease of protection successes. Further DMI derivatives (e.g., tebuconazole, cyproconazole, epoxiconazole) were introduced to the German fungicide market at the beginning of the 90's. A reduced sensitivity with a MRF between 10 to 20, depending on the compound, was, however, already present when these derivatives were introduced onto the market due to the positive cross-resistance of the pathogen towards all DMI compounds. This is also one of the reasons, why they were frequently sold in combination with a, non-cross-resistant, partner.

Since the mid 90's only comparatively small sensitivity fluctuations of wheat powdery mildew towards triazoles could be observed. The sensitivity situation towards most compounds remained stable, whereby regional differences, which were present at the beginning of the 90's, were resolved in the last few years via wind dispersal. A relatively homogeneous MRF level has now been attained. Factors promoting resistance formation towards triazoles and forces that restrain these, are presently holding themselves in balance in many places within South Germany. The reasons lie, on the one hand, in the biology of the pathogen (sexual recombination of the fungus and oligo-/polygenic control of the DMI resistance formation), on the other hand, in a decrease of selection pressure by the individual triazoles during the last years. Three factors are the cause: First of all, mixed preparations are being increasingly used, whereby the partner often takes on the main role during the control of powdery mildew. In some cases, this results into additional synergy effects, which strengthen the effect of the individual components (hitch-hiking effect). Secondly, the diversity of compounds that are available has increased. And thirdly, the application of fungicide is generally stagnating, which is being attributed to the harsh economic setting and the increase in the proportion of (semi)resistant varieties in the cultivated area. Due to the stabilisation of the sensitivity situation towards triazoles, the practical experiences with the DMI derivatives can be transferred from 2000 to the cultivation year 2001.

The MRF levels of the single triazole derivatives are as follows:

Compound	**MRF Value** (see above for low regional differences)
Triadimenole	30 - 70
Propiconazole	15 - 30
Tebuconazole	15 - 25
Cyproconazole	10 - 15
Epoxiconazole	15 - 30

B) Morpholines / piperidines / spiroketalamines

Towards fenpropimorph:

A measurable sensitivity adaptation of the pathogen is also present with fenpropimorph, which has been on the market since the beginning of the 80's. However, the sensitivity adaptation happened relatively slowly because the compound acts at different sites of the fungal sterol biosynthesis. Fenpropimorph adaptation only became apparent in South Germany in the 90's, although the compound experienced a relatively intensive selection pressure. The past shift led to MRF's up to 10 everywhere in the study area, whereby hardly any isolates with the original sensitivity towards Fenpropimorph were found. The general development is still to be classified as moderate. Our analyses showed, over the years, that a biological barrier is present at a MRF of about 10, which blocks a continued formation of resistance towards fenpropimorph, and that a further loss of sensitivity is only possible under comparably high selection pressure. The current situation of sensitivity to fenpropimorph cannot, so far, be classified as very risky, and the effectiveness of 'Corbel' can, in general, still be evaluated as 'good'. The basis for this evaluation is, however, an application with the entire recommended quantity. The estimation does not refer to the splitting of the preparations with strongly reduced quantities of the compound. When taking the present sensitivity situation into account, the remaining reserves of compounds have been used so much, that there is a real danger of straining it when using such an application strategy. It is advisable to use the recommended application quantities, especially when high infection pressures are present.

Towards fenpropidin:

Fenpropidin has been released in Germany since 1995. Due to the positive cross-resistance of the pathogen towards the morpholine fenpropimorph (see above) and towards the piperidine fenpropidin, a sensitivity level reduced by a factor of four to eight was already present within the study area when the latter was introduced to the market. Similar MRF values were also found in 2000, so that hardly any modifications arose within the population. The MRF values, which can still be classified as moderate, should generally not have a serious effect in the field. One can therefore assume that a good protection against powdery mildew will occur with the sole product 'Zenit M' and the application of the entire recommended quantity (see remarks to fenpropimorph). However, isolates with clearly reduced fenpropidin sensitivity (resistance factors > 20/30) have been found in the last few years. Their proportion of the total population is presently still relatively small (< 20 %), but should be monitored carefully.

Towards spiroxamine:

Spiroxamines were introduced to the German fungicide market in 1997. Being a spiroketalamine, it belongs to the compounds of the SBI group as fenpropimorph and fenpropidin. Due to positive cross-resistance of wheat powdery mildew towards fenpropimorph/fenpropidin on the one hand and spiroxamine on the other hand, a sensitivity level reduced by a MRF from approximately four to six was present in the study area at introduction of the compound. A positive note is that the sensitivity level has not yet changed measurably since that time. The values can be classified as still moderate. A thus far observed success in protection can also be expected in 2001.

C) Strobilurins

The strobilurins are still a relatively new class of compounds, which was introduced on the German or European fungicide market for the first time in 1996 and which enjoyed a rapid - not least because of its pronounced physiological effects - distribution and a relatively intensive application. Due to its, up to that point, new mechanism (an intervention into the oxygen transport of the fungus) no cross-resistance to already existent compounds on the market was present. The sensitivity level within Europe was, therefore, on original or as yet unselective levels before applications started. Little was known about the mechanism of any resistance formation up to the 1998 studies. A surprisingly high proportion of isolates with qualitative strobilurin resistance of > 50 % occurred in some areas of Northern Germany (eastern SH and Ni, western MV) for the first time in 1998. This poses an extremely serious problem due to the disruptive resistance selection, particularly because the adaptation process can be rapidly expressed within one season and because the pathogen reacts with positive cross-resistance towards all current strobilurin derivatives on the market: **kresoxim-methyl**, **azoxystrobin** and **trifloxystrobin**. The results, obtained for one strobilurin compound can therefore be directly transferred to the other two strobilurins.

The results of the current resistance situation of wheat powdery mildew are represented in Table 6. The proportion of resistant powdery mildew within the sample or regional population supplies a clear statement for the local effectiveness of the strobilurins (see 'Background'!). Strong regional differences are currently present. While strobilurins offer no or only a small protective effect against wheat powdery mildew in the study area of Northern Germany, a "good" to "noticeable" protective effect can be expected in South Germany. However, clear losses in effectiveness need to be taken into account within this area, in case of a stronger, persisting powdery mildew epidemic.

Table 6: Strobilurin-resistance of wheat powdery mildew in air borne samples from different regions of MV, NI, TH, HE, RP, BW and BY, 2000

Region	Date	n	Res. isolates	% res. isolates
Mecklenburg-Western Pomerania:				
Lübeck-Rostock	09.07.	50	50	**100**
Rostock-Neubrandenburg	01.06.	50	28	**56**
Neubrandenburg-Prenzlau	01.06.	50	27	**54**
Lower Saxony:				
Hannover-Kassel	08.07.	50	46	**92**
Thuringia:				
Nordhausen-Erfurt	11.06.	41	12	**29**
Erfurt-Gera-Altenburg	11.06.	13	3	**23**
Hof-Gera	01.07.	17	2	**12**
Hessen:				
Warburg-Kassel-Fulda	28.06.	31	18	**58**
Rhineland-Palatinate:				
Rheinbach-Koblenz	23.06.	10	3	**30**
Koblenz-Trier	23.06.	18	4	**22**
Speyer-Bingen	23.06.	48	2	**4**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	50	22	**44**
Karlsruhe-Basel	10.06.	10	2	**20**
Karlsruhe-Ulm	10.06.	50	4	**8**
Stuttgart-Singen	10.06.	13	3	**23**
Bavaria:				
Schweinfurt-Rothenburg	05.06.	41	3	**7**
Hof-Nürnberg	05.06.	21	3	**14**
Hof-Regensburg	05.06.	10	2	**20**
Nürnberg-Freising	05.06.	37	7	**19**
Ulm-Freising	10.06.	43	10	**23**
Niederbayern	05.06.	46	11	**24**

D) Chinolines

Towards quinoxyfen:

The chinolin derivative quinoxyfen was available for the first time in 1997 for the protection of cereal against powdery mildew. The derivative is specific to powdery mildew and can only be applied as a protective strategy, since it prevents the formation of appressoria and thus averts the first step in the infection process of the pathogen. However, quinoxyfen shows no effect after successful penetration of the pathogen into the epidermis of the leaf, so that protection of the already present and visible powdery mildew is not possible. The optimal application time is, therefore, during the early stage of the powdery mildew epidemic or later in combination with a good curative partner. Quinoxyfen is so far characterised by an outstanding long-term mildew control.

Even the examinations in 2000, with an extended study area (Table 7), did not discover signs of **any** resistance formation regarding quinoxyfen sensitivity of wheat powdery mildew, both qualitative or quantitative. The population structure therefore still corresponds everywhere to the unselected, original population. Quinoxyfen is still effective without reservation in the entire study area and is therefore very well suited for the protection against powdery mildew, especially as partner when alternating or combining compounds.

Since quinoxyfen is used more often and on a larger scale, mainly due to the resistance formation of wheat powdery mildew to the strobilurins, the examination of the following years will show whether adaptation will occur and in what form this adaptation will happen. Only hypotheses are currently available to explain the method of a possible sensitivity adaptation or resistance formation of the pathogen towards quinoxyfen. DOW AgroSciences therefore assumes a rather quantitative adaptation process. The examinations mentioned in this paper will be definitely suitable to detect both forms, should sensitivity adaptation or resistance formation occur.

Table 7: Adaptation of wheat powdery mildew towards quinoxyfen in air borne samples from different regions in MV, NI, TH, HE, RP, BW and BY, 2000: The proportion of isolates is listed within the samples with quantitatively or qualitatively reduced sensitivity to the a.i.

Region	Date	n	Isolates with red. sensitivity	% isolates with red. sensitivity
Mecklenburg-Western Pomerania:				
Rostock-Neubrandenburg	01.06.	12	0	**0**
Neubrandenburg-Prenzlau	01.06.	12	0	**0**
Lower Saxony:				
Hannover-Kassel	08.07.	20	0	**0**
Thuringia:				
Nordhausen-Erfurt	11.06.	12	0	**0**
Erfurt-Gera-Altenburg	11.06.	12	0	**0**
Hessen:				
Warburg-Kassel-Fulda	28.06.	12	0	**0**
Rhineland-Palatinate:				
Rheinbach-Koblenz	23.06.	10	0	**0**
Koblenz-Trier	23.06.	12	0	**0**
Speyer-Bingen	23.06.	12	0	**0**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	12	0	**0**
Karlsruhe-Basel	10.06.	11	0	**0**
Karlsruhe-Ulm	10.06.	12	0	**0**
Stuttgart-Singen	10.06.	11	0	**0**
Bavaria:				
Schweinfurt-Rothenburg	05.06.	12	0	**0**
Hof-Nürnberg	05.06.	12	0	**0**
Hof-Regensburg	05.06.	8	0	**0**
Nürnberg-Freising	05.06.	10	0	**0**
Ulm-Freising	10.06.	12	0	**0**
Niederbayern	05.06.	12	0	**0**

E) Anilinopyrimidine

Towards cyprodinil:

Cyprodinil was available in Germany in 1998. It had, however, already been released in France for some years. The main emphasis of the compound is not protection against powdery mildew, but rather against cereal disease such as eyespot and net blotch of cereals. The compound nevertheless represents a valuable widening of the fungicide spectrum for the protection against powdery mildew. However, the principle of sensitivity adaptation is still a possibility and the analyses of sensitivity therefore have to consider both types of adaptation towards this compound (see 'Background'). Furthermore one has to consider that - at least according to the available results - a divided sensitivity structure (≤ 1 % of the population possesses a reduced sensitivity towards cyprodinil by a factor of approximately 10) is evident within the naturally and originally occurring sensitivity distribution. This very small proportion of isolates with partially reduced cyprodinil sensitivity has, however, no noticeable negative effects in field conditions. However, one has to monitor the situation attentively to determine the extent that this fraction of isolates increases following an increase in selection pressure.

The investigations in 2000 (Table 8) show a population structure with mostly original sensitivity levels. A qualitative adaptation can not be detected and the proportion of isolates with partially reduced cyprodinil sensitivity also corresponds to expectations and does not differ significantly from the initial original-sensitive population. Cyprodinil is therefore equally well suited for the alternation and combination of compounds and can make a valuable contribution regarding the options in the context of anti-resistance management.

Table 8: Adaptation of wheat powdery mildew towards cyprodinil in air borne samples from different regions in MV, NI, TH, HE, RP, BW and BY, 2000: The proportion of isolates is listed within the samples with quantitatively or qualitatively reduced sensitivity to the a.i.

Region	Date	n	Isolates with red. sensitivity	% isolate with red. sensitivity
			quant. / qual.	quant. / qual.
Mecklenburg-Western Pomerania:				
Rostock-Neubrandenburg	01.06.	12	0	**0**
Neubrandenburg-Prenzlau	01.06.	12	0	**0**
Lower Saxony:				
Hannover-Kassel	08.07.	10	0	**0**
Thuringia:				
Nordhausen-Erfurt	11.06.	12	0	**0**
Erfurt-Gera-Altenburg	11.06.	12	0	**0**
Hessen:				
Warburg-Kassel-Fulda	28.06.	12	0	**0**
Rhineland-Palatinate:				
Rheinbach-Koblenz	23.06.	10	1 / 0	**10 / 0**
Koblenz-Trier	23.06.	12	0	**0**
Speyer-Bingen	23.06.	12	1 / 0	**8 / 0**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	12	0	**0**
Karlsruhe-Basel	10.06.	11	0	**0**
Karlsruhe-Ulm	10.06.	12	0	**0**
Stuttgart-Singen	10.06.	11	0	**0**
Bavaria:				
Schweinfurt-Rothenburg	05.06.	12	0	**0**
Hof-Nürnberg	05.06.	12	1 / 0	**8 / 0**
Hof-Regensburg	05.06.	8	0	**0**
Nürnberg-Freising	05.06.	10	0	**0**
Ulm-Freising	10.06.	12	0	**0**
Niederbayern	05.06.	12	0	**0**

2. Compound sensitivity of barley powdery mildew

The investigations of the last few years have shown a clear stabilisation in the sensitivity adaptation of barley powdery mildew towards the class of triazole compounds. The emphasis in the examinations of 2000 was therefore set on the compounds which were newly introduced to the market: strobilurins, chinolines and anilinopyrimidines.

Table 9: Practice-relevant estimation of the sensitivity situation of barley powdery mildew for the study area, 2000.
Evaluation code 0 to 10 (see above):
0: no signs of resistance formation → no loss in effectiveness
10: max. advanced sensitivity loss → full loss of efficiency

Compound	Solo-product	Evaluation of adaptation/resistance formation
Triazoles:		
Triadimenole	Baytan (Seed)	7/8
	Bayfidan (Leaf/Ear)	6
Propiconazole	Desmel	5
Tebuconazole	Folicur	5
Cyproconazole	Alto 100	3/4
Epoxiconazole	Opus, (Opus top)*	4/5
Morpholines / Piperidines / Spiroketalamines:		
Fenpropimorph	Corbel	2
Fenpropidin	Zenit M	2
Spiroxamine	Impulse	0/1
Strobilurins:		
Kresoxim-methyl	(Juwel top)*	0/(1)
Azoxystrobin	Amistar	0/(1)
Trifloxystrobin	(Stratego)*	0/(1)
Chinolines:		
Quinoxyfen	(Fortress top)*	0
Anilinopyrimidines:		
Cyprodinil	Unix	0

*only available in combination with other compounds

A) Triazoles (DMIs: Demethylisation Inhibitors)

The reasons for a further advanced adaptation of barley powdery mildew towards the respective compounds compared to wheat powdery mildew are threefold: the intensive use of the triazole derivatives triadimenole and propiconazole in the 80's, the application of triadimenole both for seed and leaf/ear treatment and the possibility of the pathogen to create dominating pathotypes in the population. Furthermore, the positive cross-resistance of barley powdery mildew towards the DMIs meant that when the triazoles, such as tebuconazole, cyproconazole or epoxiconazole, were introduced on the German market in the 90's, reduced sensitivity levels prevailed with MRFs ranging from 10 to 35, depending upon compound and region.

The adaptation dynamics slowed down at the beginning of the 90's and a stabilisation of the sensitivity situation followed until the mid 90's. Due to the wind dispersal of the pathogen, regional differences (prevalent in the 80's) increasingly disappeared during this phase. From that point in time onwards, the levels of DMI resistance in the different regions of South Germany were subject to relatively small modifications only. As in the case of wheat powdery mildew, the factors that promote the resistance formation towards triazoles and the forces, which limit resistance formation are balancing themselves out in South Germany. The causes can be explained with the biology of the pathogen (sexual recombination of the fungus and oligo-/polygenic control of the resistance formation towards DMIs, whereby the cleistothecia/ascospores seem to be more important for the annual infection cycle of wheat powdery mildew). Additionally the selection pressure exerted by the individual triazoles has decreased in the last few years. Thus mixed preparations are increasingly being used, whereby the mixing partners often take on the main role during the protection against powdery mildew. Sometimes this results in additional synergy effects, which strengthen the effect of the individual components (hitch-hiking effect). Secondly, the diversity of available compounds with different sites of action has increased. And thirdly the general fungicide application was rather restraint in the last few years, due to a harsher economic setting and the substantial increase of the proportion of resistant varieties.

Due to the stabilisation of the sensitivity situation, the practical experiences with the triazole derivatives from the last years can be transferred to the cultivation year of 2001.

The MRF levels towards the individual triazol derivatives are presently situated approximately as follows:

Compound	**MRF-Values** (see above for low regional differences)
Triadimenole	100 - 250
Propiconazole	35 - 50
Tebuconazole	30 - 50
Cyproconazole	20 - 35
Epoxiconazole	30 - 50

B) Morpholines / piperidines / spirokektalamines

Towards fenpropimorph:

While no signs of an adaptation of barley powdery mildew to fenpropimorph were detected in South Germany until 1992 (including), an initial adaptation reaction of the pathogen was registered in 1993. Distinct isolates in some samples demonstrated a reduced sensitivity by a factor of around 3 to 10. One can presently expect proportions of these isolates in the regional barley powdery mildew population to reach levels of 10/20 % within the extended study area, in some cases even higher, so that a first, yet moderate, shift is noticeable. One can nevertheless expect a good powdery mildew protection from applying fenpropimorph. Fenpropimorph is, therefore, still well suited for mixing and alternating compounds. The future development of sensitivity, however, has to be carefully monitored since gradual modifications can be expected in the coming years.

Towards fenpropidin:

A similar sensitivity situation is also present towards the piperidin compound fenpropidin, which was released in 1995. The barley powdery mildew isolates sampled in the study area still predominantly possess the original fenpropidin sensitivity. The isolates with reduced fenpropidin sensitivity usually show somewhat smaller resistance factors (≤ 5) compared to fenpropimorph, but a few show higher factors of ≥ 30. Special attention has to be given to the latter in the future. The present adaptation reaction can be characterised as "extremely moderate" and should not show any noticeable negative effects in the field. The results display a very good powdery mildew protection for the study area, which is why the piperidin compound is well suited for mixing and alternating compounds, similar to fenpropimorph.

Towards spiroxamine:

Since barley powdery mildew populations possess a positive cross-resistance towards fenpropimorph/fenpropidin and the spiroketalamine spiroxamine, similar as wheat powdery mildew, the sensitivity situation towards this compound is comparable to the two aforementioned compounds. The cross-resistance is only pronounced extremely weak (just about measurable), so that the appropriate isolates only differ slightly from the original spiroxamine sensitivity level. There is practically no restriction in the effectiveness of the fungicide due to past adaptation reactions. Spiroxamine is therefore very well suited for mixing and alternating compounds for anti-resistance management.

C) Strobilurins

Strobilurins use different sites of action (intervention into the oxygen transport of the mitochondria) than the SBI compounds (see above), which is why barley powdery mildew did not have a cross-resistance to the compounds already on the market when strobilurins were introduced. The sensitivity level, similar to wheat powdery mildew, was therefore still original and unselected before the compounds started to be applied. One has to note that barley powdery mildew (like wheat powdery mildew) follows a qualitative adaptation (see 'Background'), and that barley powdery mildew also possesses positive cross-resistance to all strobilurin derivatives present on the market. Observations to, for example, **kresoxim-methyl** can therefore be transferred directly to the two other strobilurin compounds azoxystrobin and trifloxystrobin.

A qualitative resistance formation of wheat powdery mildew (see above) with regionally extremely rapid adaptation dynamics was determined in the third year of the sometimes extensive application of the appropriate preparations. This primarily began in Northern Germany, where proportions of isolates with factors of 50-100 % were rapidly attained in regional wheat powdery mildew populations. But the proportion in South Germany also reached levels of mostly 20/30 %.

A different situation is occurring for barley powdery mildew - even in the extended study area (see Table 10). **No** isolate resistant to strobilurins could be found in 2000. This also applies to the region between Rostock and New Brandenburg, where the first resistant isolate of barley powdery mildew was found in 1999. The proportion of isolates with strobilurin resistance did not continue to increase in that area. It is probably still latently present within the study area at $\leq$ 1 %. The examination of the next years will show how rapidly this proportion increases to dimensions relevant to the practical situation. The exercised selection pressure on the pathogen and the selection time period are crucial factors in the development of resistance. These two factors can still be influenced via a suitable anti-resistance management, in order to limit the increase of isolates resistant to strobilurins in the regional population of the pathogen.

Table 10: Strobilurin-resistance of barley powdery mildew in air borne samples from different regions of MV, NI, TH, HE, RP, BW and BY, 2000

Region	Date	n	Res. isolates	% res. isolates
Mecklenburg-Western Pomerania:				
Rostock-Neubrandenburg	01.06.	29	0	**0**
Lower Saxony:				
Hannover-Kassel	02.06.	53	0	**0**
Thuringia:				
Nordhausen-Erfurt	11.06.	68	0	**0**
Erfurt-Gera-Altenburg	11.06.	33	0	**0**
Rhineland-Palatinate:				
Rheinbach-Koblenz	02.06.	20	0	**0**
Koblenz-Trier	15.06.	23	0	**0**
Speyer-Bingen-Kaiserslautern	02.06.	34	0	**0**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	16	0	**0**
Karlsruhe-Basel	10.06.	10	0	**0**
Karlsruhe-Ulm	10.06.	52	0	**0**
Stuttgart-Singen	10.06.	19	0	**0**
Bavaria:				
Schweinfurt-Rothenburg	05.06.	8	0	**0**
Hof-Nürnberg	05.06.	71	0	**0**
Hof-Regensburg	05.06.	50	0	**0**
Nürnberg-Freising	05.06.	39	0	**0**
Ulm-Freising	10.06.	9	0	**0**
Niederbayern	05.06.	12	0	**0**

D) Chinolines

Towards quinoxyfen

The chinolin derivative quinoxyfen has a new mechanism and has been on the German fungicide market for three years now. It is specific to powdery mildew and prevents the first step of the infection (formation of appressoria). Protection against latently present and visible powdery mildew infestation is not possible, so that the optimal application should take place at the beginning of the infestation or later on in combination with a good curative partner. Quinoxyfen is characterised by its continuous effect. As Table 11 demonstrates, no barley powdery mildew isolate with reduced quinoxyfen sensitivity could be found in the extended study area of the 2000 investigations. The compound concentrations in the analyses were selected in such a way that both a quantitative shift and a qualitative adaptation could have been detected. The population structure, therefore, still corresponds to the original, unselected, initial population. Since there are still gaps in the knowledge about the effective mechanisms of quinoxyfen, it is unknown if and to what extent the pathogen can adapt.

E) Anilinopyrimidine

Towards cyprodinil

Cyprodinil is a relatively new compound on the German fungicide market. It has, however, been registered in France for a few years. There is presently no cross-resistance of barley powdery mildew towards this compound and other a.i. currently on the market. Its emphasis for barley is not so much powdery mildew rather than net blotch.

The results in 2000 (Table 12) did not show any negative changes regarding an adaptation of sensitivity of barley powdery mildew to cyprodinil. The compound concentrations were again selected in such a way so that both a quantitative shift and a qualitative adaptation in the analyses would have been detected. In contrast to wheat powdery mildew (see above), no isolate with partially reduced cyprodinil sensitivity could be found. An originally sensitive population structure is present everywhere in the examined regions. The compound is therefore well suited for the integration into anti-resistance management and can make a valuable contribution, for example in compound alternations.

Table 11: Adaptation of barley powdery mildew towards quinoxyfen in air borne samples from different regions in MV, TH, HE, RP, BW and BY, 2000: The proportion of isolates is listed within the samples with quantitatively or qualitatively reduced sensitivity to the a.i.

Region	**Date**	**n**	**Isolates with red. sensitivity**	**% isolates with red. sensitivity**
Mecklenburg-Western Pomerania:				
Rostock-Neubrandenburg	01.06.	12	0	**0**
Thuringia:				
Nordhausen-Erfurt	11.06.	10	0	**0**
Erfurt-Gera-Altenburg	11.06.	10	0	**0**
Rhineland-Palatinate:				
Rheinbach-Koblenz	23.06.	10	0	**0**
Koblenz-Trier	23.06.	10	0	**0**
Speyer-Bingen	23.06.	10	0	**0**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	10	0	**0**
Karlsruhe-Basel	10.06.	10	0	**0**
Karlsruhe-Ulm	10.06.	10	0	**0**
Stuttgart-Singen	10.06.	10	0	**0**
Bavaria:				
Schweinfurt-Rothenburg	05.06.	8	0	**0**
Hof-Nürnberg	05.06.	10	0	**0**
Hof-Regensburg	05.06.	10	0	**0**
Nürnberg-Freising	05.06.	10	0	**0**
Ulm-Freising	10.06.	9	0	**0**
Niederbayern	05.06.	10	0	**0**

Table 12: Adaptation of barley powdery mildew towards cyprodinil in air borne samples from different regions in MV, TH, RP, BW and BY, 2000: The proportion of isolates is listed within the samples with quantitatively or qualitatively reduced sensitivity to the a.i.

Region	Date	n	Isolates with red. sensitivity	% isolate with red. sensitivity
			quant. / qual.	quant. / qual.
Mecklenburg-Western Pomerania:				
Rostock-Neubrandenburg	01.06.	12	0	**0**
Thuringia:				
Nordhausen-Erfurt	11.06.	10	0	**0**
Erfurt-Gera-Altenburg	11.06.	10	0	**0**
Rhineland-Palatinate:				
Rheinbach-Koblenz	23.06.	10	0	**0**
Koblenz-Trier	23.06.	10	0	**0**
Speyer-Bingen	23.06.	10	0	**0**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	10	0	**0**
Karlsruhe-Basel	10.06.	10	0	**0**
Karlsruhe-Ulm	10.06.	10	0	**0**
Stuttgart-Singen	10.06.	10	0	**0**
Bavaria:				
Schweinfurt-Rothenburg	05.06.	8	0	**0**
Hof-Nürnberg	05.06.	10	0	**0**
Hof-Regensburg	05.06.	11	0	**0**
Nürnberg-Freising	05.06.	10	0	**0**
Ulm-Freising	10.06.	10	0	**0**
Niederbayern	05.06.	10	0	**0**

3. Compound sensitivity of brown rust of wheat

Strobilurins:

The analyses of sensitivity of brown rust of wheat in 2000 were concentrated on the determination of resistance formation towards the strobilurin derivatives. Investigation of sensitivity to the triazoles in South Germany had been undertaken in previous years, whereby the experiments demonstrated a very slow quantitative sensitivity adaptation.

No resistant isolate was found in the study area when examining the strobilurin sensitivity of brown rust of wheat in 2000 (Table 13). The tests were again laid out in such a way to make any possible quantitative adaptation visible.

The adaptation situation of brown rust of wheat is still perfectly calm in contrast to the situation with wheat powdery mildew. No loss of efficiency due to resistance formation is therefore expected in 2001.

Practice-relevant estimation of the sensitivity situation with brown rust of wheat for the investigation area, 2000; Evaluation code 0 to 10 (see above, 'Background'):

0: no signs of a resistance formation → no effect losses

10: max. advanced sensitivity loss → full loss of efficiency

Evaluation number: 0

4. Compound sensitivity of brown rust of rye

Strobilurin:

The analyses of sensitivity in 2000 were also concentrated on the determination of resistance formation of brown rust of rye towards the strobilurin derivatives. As Table 14 demonstrates, no resistant or quantitatively adapted isolates were found in the investigations, despite substantial epidemics in the different rye cultivating regions and despite considerable use of primarily azoxystrobin. The adaptation situation of brown rust of rye appears as calm as with brown rust of wheat.

Practice-relevant estimation of the sensitivity situation with brown rust of rye for the investigation area, 2000; Evaluation code 0 to 10 (see above, 'Background'):

0: no signs of a resistance formation → no effect losses

10: max. advanced sensitivity loss → full loss of efficiency

Evaluation number: 0

Table 13: Strobilurin-resistance of brown rust of wheat in air borne samples from different regions of MV, NI, TH, HE, RP, BW and BY, 2000

Region	Date	n	Res. isolates	% res. isolates
Mecklenburg-Western Pomerania:				
Schwerin-Oranienburg	09.07.	10	0	**0**
Rostock-Neubrandenburg	01.06.	5	0	**0**
Lower Saxony:				
Braunsch.-Salzg.-PortaWestf.	08.07.	10	0	**0**
Thuringia:				
Nordhausen-Erfurt	11.06.	30	0	**0**
Erfurt-Gera-Altenburg	11.06.	18	0	**0**
Hof-Gera	01.07.	12	0	**0**
Rhineland-Palatinate:				
Rheinbach-Koblenz	23.06.	10	0	**0**
Speyer-Bingen-Kaiserslautern	23.06.	10	0	**0**
Hessen:				
Warburg-Kassel-Fulda	28.06.	10	0	**0**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	10	0	**0**
Karlsruhe-Basel	10.06.	24	0	**0**
Bavaria:				
Schweinfurt-Rothenburg	05.06.	18	0	**0**
Hof-Nürnberg	05.06.	6	0	**0**
Nürnberg-Freising	05.06.	10	0	**0**
Niederbayern	05.06.	10	0	**0**

Table 14: Strobilurin-resistance of brown rust of rye in air borne samples from different regions of MV, NI, BW and BY, 2000

Region	Date	n	Res. isolates	% res. isolates
Mecklenburg-Western Pomerania:				
Mölln-Wittstock	01.06.	10	0	**0**
Rostock-Wittstock	01.06.	10	0	**0**
Lower Saxony:				
Hamburg-Hannover	02.06.	20	0	**0**
Baden-Wuerttemberg:				
Hockenheim-Karlsruhe	10.06.	25	0	**0**
Bavaria:				
Crailsheim-Nürnberg	05.06.	15	0	**0**
Nürnberg-Freising	11.06.	10	0	**0**

5. Compound sensitivity of *Septoria tritici*

Analyses of sensitivity of *Septoria tritici* were undertaken in 2000 both towards triazole derivatives, and especially towards the strobilurins.

A) Triazole

First investigations were started with a few field samples from the study area both *in vivo* (test assortments from leaf segments, see 'Introduction') and *in vitro* (fungus grown on growth medium, so-called microtiter test). The results illustrate that this pathogen has also undergone quantitative adaptation towards this group of compounds. However, since no originally sensitive isolates are available for comparison, it is difficult to make predictions on the level of the adaptation. If one considers the available literature, then the adaptation - similar as with wheat powdery mildew - probably occurred during the mid 90's, and the present sensitivity situation is shaped more by a certain stability on the attained level. Simultaneously, differences in the adaptation level seem to be present towards the different triazole derivatives. After our first investigations, the loss of sensitivity towards **epoxiconazole** seems to have reached relatively low levels, which could explain the very good effect of epoxiconazole towards *Septoria tritici*. Further investigations need to draw a clearer picture in the following years.

B) Strobilurins

Extensive investigations were undertaken to examine any adaptation of the pathogen to the strobilurin derivatives. Only field samples, which do not show such a high representation as the samples from the arial spore inoculum (see 'Introduction'), could be used. All field samples for each "Bundesland" of the Federal Republic were therefore summarized, in order to be able to make a prediction.
As Table 15 reveals, no isolate with the appropriate resistance formation could be found in the study area, although azoxystrobin, in particular, has exerted a strong selection pressure here for some years. The original sensitivity has thus far remained, or modifications are not yet visible, and the effectiveness of strobilurin compounds should not be reduced for the 2001 season.

Practice-relevant estimation of the sensitivity situation with *Septoria tritici* for the investigation space, 2000; Evaluation code 0 to 10 (see above, Background):

0: no signs of a resistance formation → no effect losses
10: max. advanced sensitivity loss → full loss of efficiency

Evaluation number: 0

Table 15: Strobilurin-resistance of *Septoria tritici* in field samples from different sites of MV, NI, TH, HE, RP, BW and BY, 2000

Region	Sites	n	Res. Isolates	% res. isolates
Mecklenburg-Western Pomerania	4	19	0	**0**
Lower Saxony (East)	15	58	0	**0**
Thuringia	3	11	0	**0**
Hessen	5	20	0	**0**
Rhineland-Palatinate	4	20	0	**0**
Baden-Wuerttemberg	7	35	0	**0**
Bavaria	12	40	0	**0**

6. Compound sensitivity of barley net blotch (*Drechslera teres*)

Strobilurins:

The pathogen of barley net blotch is, in principle, an easily adaptable pathogen, just as wheat and barley powdery mildew. It is the more amazing that despite, in some cases, substantial selection pressure from strobilurin compounds, especially azoxystrobin, no adaptation reaction has occurred so far in the study area (see Table 16). At least their proportion is still so small that appropriate isolates did not yet occur in the samples. The analyses of sensitivity considered thereby again both any quantitative as well as qualitative resistance formation. An unrestricted effectiveness should therefore still be expected in the 2001 season.

Practice-relevant estimation of the sensitivity situation with barley net blotch for the investigation area, 2000; Evaluation code 0 to 10 (see above, 'Background'):

0: no signs of a resistance formation → no effect losses

10: max. advanced sensitivity loss → full loss of efficiency

Evaluation number: 0

Table 16: Strobilurin-resistance of *Drechslera teres* (net blotch of barley) in air borne samples from different regions of NI, TH, HE, RP, BW and BY, 2000

Region	Date	n	Res. isolates	% res. isolates
Lower Saxony:				
Hannover-Kassel	08.07.	20	0	**0**
Thuringia:				
Nordhausen-Erfurt	11.06.	5	0	**0**
Erfurt-Gera-Altenburg	11.06.	15	0	**0**
Gera-Hof	11.06.	5	0	**0**
Hessen:				
Warburg-Kassel-Fulda	08.07.	10	0	**0**
Rhineland-Palatinate:				
Rheinbach-Koblenz	01.06.	5	0	**0**
Speyer-Bingen-Kaiserslautern	01.06.	5	0	**0**
Baden-Wuerttemberg:				
Sinsheim-Crailsheim	15.06.	7	0	**0**
Bavaria:				
Nürnberg-Freising	05.06.	10	0	**0**