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RESISTANCE SITUATION WITH FUNGICIDES IN CEREALS

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Abstract

Today, the farming community is very dependent on effective fungicides being available in order to stabilize yields and reduce the losses from the development of disease epidemics in cereals. Common practice in many countries is to spray winter wheat two to three times per season and barley crops one to two times depending on the cultivar and disease severity. Currently, wheat often responds by between 1 to 2 t ha^{-1} for fungicide control measures and barley by 0.5–1.0 t ha^{-1} depending on weather and disease pressure.

Intensive use of fungicides for control of major diseases in wheat like septoria leaf blotch, (*Mycosphaerella graminicola*), powdery mildew (*Blumeria graminis*) and eyespot (*Oculimacula yallundae* and *O. acuformis)* has over the years been found to give rise to development of fungicide resistance in relation to benzimidazols, DMIs and strobilurins. In barley, changes have been seen for powdery mildew, scald (*Rhynchosporium secalis)* and net blotch (*Pyrenophora teres)*. Today, the main fungicides for disease control in cereals are triazols, strobilurins, morpholines and carboxamides and chlorothalonil.

The major changes seen in sensitivity to fungicides make it highly relevant and essential to follow the development of fungicide resistance in order to be able to adjust recommendations and avoid unnecessary use of fungicides which are no longer effective.

Key words: fungicides, resistance, cereal disease.

Resistance management

There are examples of fungicide resistance in the majority of the modern fungicide groups currently available. There is an on-going debate as to whether there is such a thing as a successful anti-resistance strategy. However, there are few examples where a planned or reactive strategy has been successful in slowing down or preventing the further development of resistance. Where such a strategy has 'worked' it is often unclear why – and so the industry continues to apply the general principles promoted by FRAC. These principles are primarily:

- Limiting the exposure of the pathogen population to the fungicide, mainly by reducing the number of applications per season.
- Avoiding the use of fungicides in an eradicant situation, where the target pathogen is already well established in the crop.
- Mixing or alternating fungicides with different modes of action.
- Manipulating dose (generally described as avoiding multiple low doses and promoting the use of high doses).

Some of these principles are based on general assumptions, some are impracticable, and others contradicted by experimental evidence. The one principle that cannot be argued against is that of limiting the exposure of the pathogen population. This can only be achieved by reducing disease pressure by whatever means possible including genetic resistance, cultural controls, etc.

In most of Europe, the main disease of wheat is septoria leaf blotch and this disease traditionally requires several treatments in order to avoid major losses. Control of this disease relies almost entirely on the use of triazole fungicides. Few alternatives are available and none of them has the curative activity of the triazoles.

Dose as an issue

Denmark has for more than 15 years recommended appropriate and reduced dosages of fungicides as part of an overall aim of reducing cost as well as impact on the environment to avoid using pesticides. The impact on fungicide resistance from these low dose strategies has often given rise to discussions and some scientists have claimed that low dosages increased the risk of developing resistance. No data have, however, been able to fully support this hypothesis and in recent years data from strobilurins have, by contrast, shown that higher dosages increase the selectivity and likelihood of developing resistance to strobilurins /Fraaije et al., 2003/ and the triazoles /Mavroidi, shaw, 2002/. Models predicting the impact from low dosages have similarly suggested that selection for resistance will usually be reduced by using decreased dosages /Shaw, 2000/. The debate about dosages has also been jeopardized by the fact that the full rate of one product may give the same level of control as ¼ rate of another product. Also, the differences obtained with respect to optimizing the timing of control measures /Jørgensen et al., 2003/ have shown that an effective dose is very dependent on several factors making it irrelevant to take the simple approach of just recommending full rate at any time. Generally speaking, the farmers should aim at using the most effective fungicides and adjusting dose according to disease level. The disease level should be kept at an economically acceptable level based on the experiences from achieved net yield responses /Jørgensen, Nielsen, 2000/.

Fungicide groups

Strobilurins

Strobilurins were introduced in Europe in 1996 and soon afterwards resistance to powdery mildew (*Blumeria graminis)* was found in wheat and from 2003 resistance similarly occurred in septoria leaf blotch (*Mycosphaerella graminicola)*. As an indication of the fast development, the level of G143A mutations in the septoria population in Denmark increased from 3% to 81% going from spring 2003 to summer 2004. Similarly, fast development was found in many neighbouring countries /Leadbeater, 2005/. Despite the present widespread occurrence of the G143A mutation in the septoria population the strobilurins have still in many situations been found to add some benefit when used; this has been found in Denmark as well as in the UK /Clark et al., 2005/.

In 2003 the first reports on strobilurin resistance in tan spot (*Pyrenophora tritici-repentis*) populations in wheat were found /Sierotzki et al., 2007/. For this pathogen both F129L and G143A mutations have been reported in the Danish population. In 2007, approximately 40–50% of the tested isolates were found to have high EC_{50} values (>10 ppm). These isolates have also been found to have the G143A mutation. Strobilurin resistance in the tan spot population has been found to variably influence the field performance. In several cases, however, a noticeable drop in field performance has been found. This has led to a general change in the recommendation for control of tan spot and today the efficacy of the strobilurins is regarded as too uncertain and triazoles are generally recommended.

So far only minor problems with QoI resistance has been found among barley diseases. Only powdery mildew (*Blumeria graminis* f. sp. *hordei*) has shown low levels of resistance. In 2008 focus will be to investigate the net blotch population for the F129 L mutation, which has been found widespread in France and the UK and which has been found to reduce the efficacy of some of the strobilurins. Today, only one treatment with strobilurins per season is recommended in the hope that this will delay the development of further resistance problems in barley.

The area treated with strobilurins has been highly influenced by the strategies which have been recommended over the years (Figure 1). The use of pesticides in Denmark is measured as a Treatment Frequency Index (TFI), which is equivalent to the number of full dosages applied per season /Jørgensen, Kudsk, 2006/. In winter cereal the total TFI has over the years varied between 0.6 and 1.0. When strobilurins were first introduced, they were very much used alone, but after these first years the recommendations changed to only using mixtures of strobilurins and triazoles and finally, since the widespread resistance in the septoria population has taken place, triazoles again dominate. Most of the treatments are targeted for control of septoria leaf blotch.

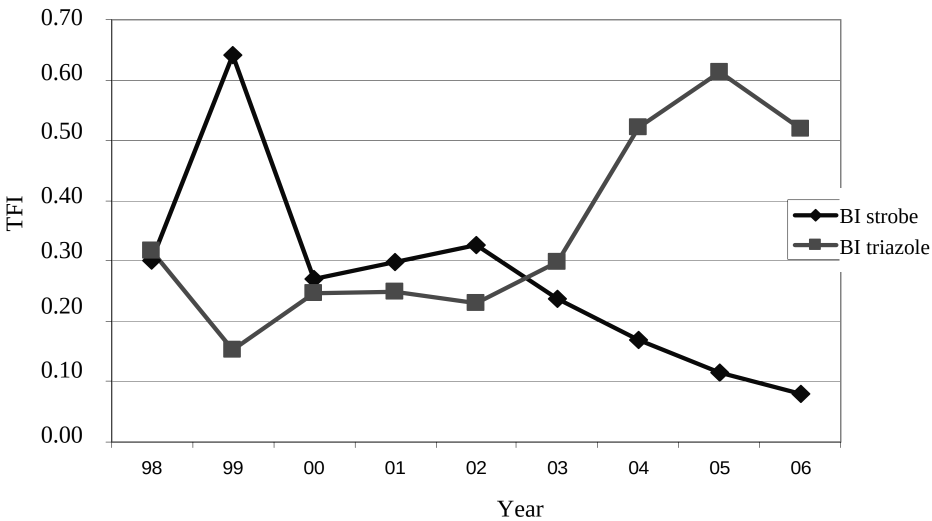

Figure 1. Treatment frequency index (TFI) for triazoles and strobilurins measured in winter cereal since the introduction of strobilurins

Triazoles

Triazoles have generally given very cost-effective control of major cereal diseases for more than 25 years in the cereal growing area of Europe. The use of triazoles increased significantly during the eighties. When first authorized, most of the triazoles were approved for control of powdery mildew in cereals in general. The efficacy on barley mildew did, however, drop significantly during the eighties. This led to withdrawal of the biological approval for control of barley mildew using propiconazole in 1996 in Denmark. The basis for this withdrawal was also supported by a high resistant factor (RF = 80–120), which indicated a large shift in sensitivity.

The level of control of septoria leaf blotch has been followed in field trials since the beginning of the nineties. Overall, there has been a significant drop in efficacy in several countries including France, the UK and Denmark /Clark, Paveley, 2005; Jørgensen, Thygesen, 2006/. Epoxiconazole and prothioconazole are today the most effective triazoles for control of septoria leaf blotch and the two products are widely used. Monitoring for resistance in the septoria population using an in vitro test are widely done along with tests screening for point mutations in the CYP 51-gene, which creates the basis for subdividing the septoria population into 7–8 different subpopulations, which response differently to different triazoles /Cools et al., 2005; Leroux et al., 2007/. The efficacy on the different sub-populations varies between triazoles; tebuconazole being most negatively influenced when the subpopulation R6 and R7 dominates the population (Figure 2). Due to the different subpopulations' sensitivity to triazoles, mixtures of triazoles have proved to potentially broaden the efficacy against septoria leaf blotch.

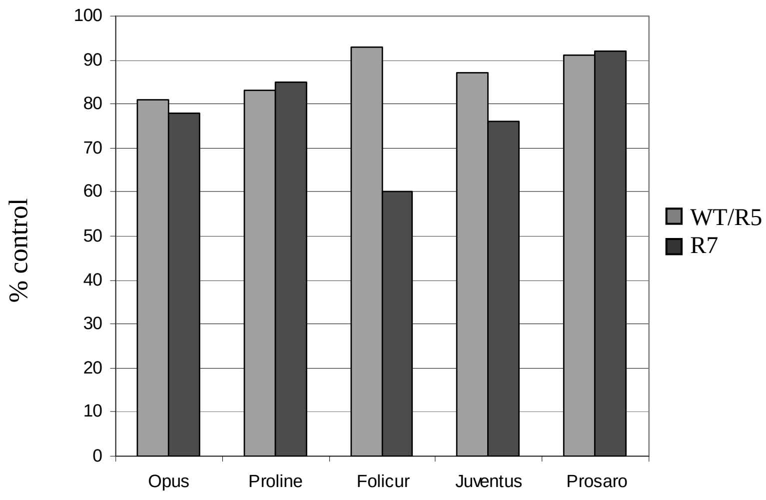

Figure 2. Control of 2 different sub-populations of septoria leaf blotch using 5 different triazoles for control. Semi-field trial with artificial inoculation belonging to R7 or WT/R5 groups (Opus – epoxiconazole 125 g l^{-1}, Proline – prothioconazole 250 g l^{-1} Folicur – tebuconazole 250 g l^{-1}, Juventus – metconazole 90 g l^{-1}, Prosaro – prothioconazole 125 g l^{-1} and tebuconazole 125 g l^{-1}).

Anilides (Carboxamides)

Carboxamides is a new group of fungicides, which very recently has been introduced as mixing partners to triazols. At present only boscalid is registered for use in cereals but several more are under development. The group works specifically on the Complex II in the mitochondrial electron transport chain interfering with respiration and ATP production in fungal cell. Fungicide resistance is known to be able to develop to this group of fungicides /Avenot et al., 2008/ although no reports have yet been found in the area of cereal diseases. In order to prolong the life of this group of fungicides it is recommended to use the carboxamides only in mixture with other fungicide groups.

New legislation

There are many concerns relating to the current EU proposals on the revision of the 91/414 regulations, particularly the re-registration of existing approvals. The current legislation is under revision and decisions made on this legislation could have dramatic consequences on EU crop production. If the final proposal includes a cut of criteria in the area of endocrine disruption it could lead to the loss of active ingredients belonging to the triazoles. This will have a major and very serious impact on disease management in Europe. Triazoles are today the core fungicides in cereal programmes and they protect other fungicides against resistance development in cereal pathogens. Loss of the triazoles will put severe pressure on the remaining fungicide groups and will increase the likelihood of resistance development, resulting in higher yield losses.

The development of resistance to any new fungicide active ingredient is inevitable as selection increases as soon as any dose is applied. Because of increased standards in safety to operators, consumers and the environment, new active ingredients are likely to have single-site modes of action. Development costs will continue to rise, limiting the number of new active ingredients with novel modes of action that are introduced to the market. Inevitably, we will have to manage diseases with fewer active ingredients than we currently have available.

Conclusions

Reduction in disease pressure by using genetical resistance and cultural means of reducing disease pressure is likely to prolong the life of fungicides in the marketplace and allow them to be used at lower doses, reducing the likely selection of fungicide resistance. Fungicides are, however, in many cases still very economical to use also in resistant cultivars, partly because varieties lack durable resistance to the major pathogens. In terms of sustainable disease control and anti-resistance strategies the following problems have to be addressed. No anti-resistance strategy is known to completely avoid or prevent resistance development. Because of new fungicides mainly being single-site active ingredients the risk will continue to be present. Increasing development costs will lead to a falling number of new active ingredients, most of which have single-site modes of action, which again will limit the arsenal of products available. The present shortage in fungicides emphasizes the importance of using other factors and tactics for disease control which can help to stabilize yields.

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