



PATHOGEN RISK LIST

(December 2013)

Purpose

Information is provided about the risk of pathogens to develop resistance to fungicides under specific agronomic conditions.

Introduction

Because no scientific criteria are available to accurately determine the risk of a pathogen to develop resistance, our classification is based on experience and reported resistance claims over the last 45 years. Generally, the risk increases when a pathogen undergoes many and short disease cycles per season, the dispersal through spores over time and space is high, sexual recombination is mandatory in the disease cycle and the competitive ability of resistant individual is at least as high as that of the wild type (in the absence of selection pressure). Furthermore, the risk is considered as high when resistance evolved already after few years of product use.

Examples to illustrate pathogen risk

It is quite easy to detect single isolates of a pathogen with reduced sensitivity to a given fungicide but only their frequency over time and space will decide whether product performance will be affected significantly. Therefore, we consider the pathogen risk as medium to high only if resistance was reported in commercial situations for more than one fungicide class.

Wheat powdery mildew is considered as high risk pathogen because resistance evolved to six different chemical classes within 2 to 5 years, whereas wheat brown rust is a low risk pathogen because no resistance evolved to the major fungicide classes (DMIs, QoIs, SDHIs, amines) used against this pathogen, even not after 25 year (DMIs). Eyespot in wheat bears a medium risk, resistance evolved to MBCs and prochloraz (DMIs) only after 10 to 15 years.

An interesting case is *Phytophthora infestans* that developed resistance quite rapidly to the phenylamide fungicides but not at all to CAA fungicides, QoI fungicides, QiI fungicides, cymoxanil, carbamates, and organotin.

Therefore, we re-classified *P. infestans* as a medium risk pathogen for all modes of action (see Table 2).

Pathogen risk classes

The following plant pathogens (Table 1) from major world markets have evolved resistance to fungicides in a time span sufficiently short to be a serious threat to the commercial success of more than one fungicide class.

Table 1: Plant pathogens accepted as showing a high risk of development of resistance to fungicides (adapted from EPPO 2002, FRAC Monograph No. 3, Russell, 2003)

Pathogen	Crop	Disease
<i>Alternaria alternata</i>	various	brown leaf spot
<i>Botrytis cinerea</i>	various, especially grapevine	grey mold
<i>Blumeria graminis</i>	wheat/barley	powdery mildew
<i>Corynespora cassiicola</i>	soybean, various	target spot
<i>Dydimella bryoniae</i>	cucurbits, various	fruit rot
<i>Mycosphaerella fijiensis</i>	banana	black sigatoka
<i>Plasmopara viticola</i>	grapevine	downy mildew
<i>Pseudoperonospora cubensis</i>	cucurbits, various	downy mildews
<i>Pyricularia oryzae</i>	rice, turf	rice blast, leaf spot
<i>Ramularia collo-cygni</i>	barley	Ramularia leaf spot
<i>Sphaerotheca fuliginea</i> , <i>Podosphaera xanthii</i>	cucurbits, various	powdery mildews
<i>Venturia inaequalis</i>	apple	Scab, black spot

The following pathogens (Table 2) are regarded as posing a much lower risk because resistance is not a major problem or has been slow to develop. In some cases this is due to the pattern of product use. Cases of specific isolates being classed as resistant may be known in some instances, but in commercial practice resistance has not created major disease control problems. The EPPO Guideline does not list these and decisions on baseline production must be made on individual case reviews.

Table 2: Plant pathogens accepted as showing a medium risk of development of resistance to fungicides

Pathogen	Crop	Disease
<i>Alternaria solani</i>	potato, tomato	early blight
<i>Ascochyta pisi</i>	peas	Ascochyta blight
<i>Bipolaris maydis</i>	maize	leaf blight
<i>Bremia lactucae</i>	lettuce	downy mildew
<i>Cercospora beticola</i>	sugar beet	leaf spots
<i>Cercospora kikuchii</i>	peanuts, beans, various	leaf blight
<i>Cercospora sojina</i>	soybean	frogeye leaf spot
<i>Colletotrichum gloeosporoides</i>	various	anthracnose
<i>Erysiphe necator</i> *	grapevine	powdery mildew
<i>Gibberella fujikuroi</i> *	rice	bakanae
<i>Leveillula taurica</i>	pepper	powdery mildew
<i>Microdochium nivale</i>	cereals, turf	snow mold
<i>Monilinia</i> spp.	various	blossom and fruit rot
<i>Mycosphaerella graminicola</i> (<i>Zymoseptoria tritici</i>)	wheat	leaf spot
<i>Mycosphaerella musicola</i>	banana	yellow sigatoka
<i>Mycosphaerella pinodes</i>	pea	blight, purple spot
<i>Mycovellosiella natrassii</i>	eggplant	leaf mold
<i>Oculimacula</i> spp.	wheat/barley	eyespot
<i>Penicillium digitatum</i>	various	green mold
<i>Penicillium expansum</i>	various	blue mold
<i>Peronospora</i> spp.	various	downy mildews
<i>Pestalotiopsis longiseta</i>	tea, various	grey blight
<i>Phyllosticta citricarpa</i>	citrus	black spot
<i>Phytophthora infestans</i>	potato/tomato	late blight
<i>Pseudoperonospora humuli</i>	hops	downy mildew
<i>Pyrenophora teres</i>	barley	net blotch
<i>Pyrenophora tritici-repentis</i>	wheat	tan spot
<i>Sclerotinia homoeocarpa</i>	turf, various	dollar spot
<i>Setosphaeria turcica</i>	maize	Northern leaf blight
<i>Sphaerotheca macularis</i>	strawberry, various	powdery mildew
<i>Stemphylium vesicarium</i>	asparagus	purple spot
<i>Venturia carpophila</i>	stone fruits, almonds	scab
<i>Venturia cerasi</i>	cherry	scab
<i>Venturia nashicola</i>	Chinese pear	scab
<i>Venturia pirina</i>	pear	scab
* The EPPO Guideline lists these pathogens as high risk pathogens of which baseline sensitivity is normally requested		

For certain pathogens, resistance occurred only to one chemical class but not to others and therefore, the pathogen is considered as low risk pathogen. Typical pathogens and diseases are given in Table 3. In some cases the financial outlay in establishing baselines will not be justified by the small markets involved irrespective of their risk of resistance development. Pathogens in this group are of local importance, but in commercial market terms are often considered as minor pathogens. Decisions on baseline production must be made on a case by case basis.

Table 3: Plant pathogens with low risk of development of resistance to fungicides or of minor commercial importance

Pathogen	Crop	Disease
<i>Cochliobolus miyabeanus</i>	rice	brown spot
<i>Fusarium</i> spp.	various	Fusarioses
<i>Guignardia bidwellii</i>	grapes	black rot
<i>Helminthosporium solani</i>	potato	silver scurf
<i>Hemileia vastatrix</i>	coffee	rust
<i>Leptosphaera</i> (= <i>Stagonospora</i>) <i>nodorum</i>	wheat	leaf spot
<i>Neofabraea</i> spp.	apples, pears	bull's eye rot
<i>Phakopsora pachyrhizi</i>	soybean	Asian rust
<i>Phomopsis viticola</i>	grapes	cane and leaf spot
<i>Phytophthora cactorum</i>	various	damping off, crown rot
<i>Podosphaera leucotricha</i>	apple	powdery mildew
<i>Puccinia</i> spp.	wheat/barley, various	rusts
<i>Pythium</i> spp.	various	damping off
<i>Rhizoctonia</i> spp.	various	foot and root rot
<i>Rhynchosporium secalis</i>	barley	scald
<i>Sclerotinia sclerotiorum</i>	various	white mold
<i>Sclerotium</i> spp.	various	blight
<i>Taphrina deformans</i>	peaches, almonds	leaf curl
<i>Tilletia</i> spp.	cereals	bunts
<i>Ustilago</i> spp.	cereals	smuts

When the pathogen risk is plotted against the inherent resistance risk of the fungicide class, the combined resistance risk for each pathogen/fungicide combination can be estimated (Figure 1).

Figure 1: Combined resistance risk diagram based on inherent fungicide risk and inherent pathogen risk (* only most important classes and groups mentioned) (according to FRAC Monograph No. 2, by K.J. Brent and D.W. Hollomon, 2007, ** SDHI fungicides have been moved from medium to medium to high risk)

↓ Fungicide Classes *	↓ Fungicide Risk	Combined Risk		
benzimidazoles dicarboximides phenylamides QoI fungicides SDHI fungicides**	high = 3	3	6	9
SBI fungicides anilinopyrimidines phenylpyrroles phosphorothiolates	medium = 2	2	4	6
multi site fungicides (e.g.dithiocarbamates Copper, Sulphur) MBI-R inhibitors SAR inducers	low = 1	1	2	3
Pathogen risk →		low = 1	medium = 2	high = 3
Pathogen groups * →		seed borne pathogens (e.g. <i>Pyrenophora</i> spp. <i>Ustilago</i> spp.) soil-borne pathogens (e.g. <i>Phytophthora</i> spp.) rust fungi <i>Rhizoctonia</i> spp.	<i>Rhynchosporium secalis</i> <i>Septoria tritici</i> <i>Oculimacula</i> spp.	<i>Blumeria graminis</i> <i>Botrytis cinerea</i> <i>Penicillium</i> spp. <i>Magnaporthe grisea</i> <i>Venturia inaequalis</i> <i>Mycosphaerella fijiensis</i>

The pathogen risk should be estimated also in regard to the local intensity of disease development that is based on weather conditions, fertilization, irrigation, cultural practices and degree of resistance of cultivars. Therefore, we propose to modify the risk diagram in the following manner (Figure 2). Detail can be found in the article written by KH Kuck, "Fungicide Resistance Management in a New Regulatory Environment", in the Proceedings of the Reinhardtsbrunn Symposium 2004 (Modern fungicides and antifungal agents, Dehne, Gisi, Kuck, Russell, eds., BCPC 2005).

Figure 2: Combined resistance risk diagram based on inherent fungicide risk, inherent pathogen risk, and agronomic risk (* only most important classes and groups mentioned, ** medium to high risk) (modified according to Kuck, 2005)

↓ Fungicide Classes *	↓ Fungicide Risk	Combined Risk			↓ Agronomic Risk
benzimidazoles dicarboximides phenylamides QoI fungicides SDHI fungicides**	high = 6	6 3 1.5	12 6 3	18 9 4.5	high = 1 medium = 0.5 low = 0.25
SBI fungicides anilinopyrimidines phenylpyrroles	medium = 4	4 2 1	8 4 2	12 6 3	high = 1 medium = 0.5 low = 0.25
multi site fungicides (e.g.dithiocarbamates) MBI-R inhibitors SAR inducers	low = 1	1 0.5 0.25	2 1 0.5	3 1.5 0.75	high = 1 medium = 0.5 low = 0.25
Pathogen risk →		low = 1	medium = 2	high = 3	
Pathogen groups * →		seed borne pathogens (e.g. <i>Pyrenophora</i> sp. <i>Ustilago</i> sp.) soil-borne pathogens (e.g. <i>Phytophthora</i> sp.) rust fungi <i>Rhizoctonia</i> sp. <i>Fusarium</i> sp. <i>Sclerotinia sclerotiorum</i>	<i>Erysiphe necator</i> <i>Gibberella fujikuroi</i> <i>Oculimacula</i> sp. <i>Rhynchosporium secalis</i> <i>Pyrenophora teres</i> <i>Septoria tritici</i> <i>Sclerotinia homoeocarpa</i> <i>Monilinia</i> sp. <i>Cercospora</i> sp. <i>Phytophthora infestans</i>	<i>Blumeria graminis</i> <i>Botrytis cinerea</i> <i>Plasmopara viticola</i> <i>Magnaporthe grisea</i> <i>Venturia inaequalis</i> <i>Mycosphaerella fijiensis</i>	