PATHOGEN RISK LIST

(September 2019)

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 50 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 30 years (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 organotins.
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). Yellow marking indicates pathogens, which were added to this update of the Pathogen Risk List in 2019.

Pathogen	**Crop**	**Disease**
Alternaria alternata	various	brown leaf spot
Botrytis allii	onions	neck rot
Botrytis cinerea	various, especially grapevine	grey mold
Botrytis elliptica	lilly	leaf blight
Botrytis squamosa	onions	leaf blight
Blumeria graminis	wheat/barley	powdery mildew
Corynespora cassiicola	soybean, various	target spot
Dydimella bryoniae	cucurbits, various	fruit rot
Plasmopara viticola	grapevine	downy mildew
Pseudoperonospora cubensis	cucurbits, various	downy mildews
Pseudocercospora (Mycosphaerella) fijiensis	banana	black sigatoka
Pyricularia oryzae	rice, turf	rice blast, leaf spot
Ramularia collo-cygni	barley	Ramularia leaf spot
Sphaerotheca fuliginea, Podosphaera xanthii	cucurbits, various	powdery mildews
Venturia inaequalis	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. Yellow marking indicates pathogens, which were added to this update of the Pathogen Risk List in 2019. Orange marking indicates a change in classification.

Pathogen	**Crop**	**Disease**
Albugo candida	Brassica species	white rust
Alternaria brassicicola, A. brassicae	oilseed rape and cabbage	black leaf spot, dark leaf spot
Alternaria solani	potato, tomato	early blight
Ascochyta pisi	peas	Ascochyta blight
Bipolaris maydis	maize	leaf blight
Blumeriella jaapii	sour cherry	leaf spot
Bremia lactucae	lettuce	downy mildew
Cercospora beticola	sugar beet	leaf spots
Cercospora kikuchii	peanuts, beans, various	leaf blight
Cercospora sojina	soybean	frogeye leaf spot
Colletotrichum acutatum	various	anthracnose
Colletotrichum gloeosporoides	various	anthracnose
Drepanopeziza ribis	currants	leaf spot
Elsinoe spp.	citrus	citrus scab
Erysiphe cruciferarum	powdery mildew	various
Erysiphe heraclei	powdery mildew	carrot
*Erysiphe necator**	grapevine	powdery mildew
*Gibberella fujikuori**	rice	bakanae
*Glomerella cingulata (*anamorph: *Gloeosporium fructigenum)*	pome fruit	bitter rot
*Neofabraea malicorticis (*anamorph: *Gloeosporium malicorticis)*	pome fruit	Anthracnose, storage rot
*Neofabraea perennans (*anamorph: *Gloeosporium perennans)*	pome fruit	bull´s eye rot
*Neofabraea vagabunda (*anamorph: *Gloeosporium album)*	pome fruit	bull´s eye rot, bitter rot
Leveillula taurica	pepper	powdery mildew
Monographella nivale	cereals, turf	snow mold
Monilinia spp.	various	blossom and fruit rot
Mycosphaerella brassicicola	crucifer	ringspot
Mycosphaerella graminicola (Zymoseptoria tritici)	wheat	leaf spot
Mycosphaerella musicola	banana	yellow sigatoka
Mycosphaerella nawae	kaki	circular leaf spot
Mycosphaerella pinodes	pea	blight, purple spot
Mycovellosiella nattrassii	eggplant	leaf mold
Oculimacula spp.	wheat / barley	eyespot
Oidium neolycopersici	tomatoes	powdery mildew
Penicillium digitatum	various	green mold
Penicillium expansum	various	blue mold
** The EPPO Guideline lists these pathogens as high risk pathogens of which baseline sensitivity is normally requested*		

Continuation of Table 2:

Pathogen	**Crop**	**Disease**
Peronospora manshurica	soybean	downy mildew
Peronospora spp.	various	downy mildews
Pestalotiopsis longiseta	tea, various	grey blight
Phakopsora pachyrhizi	soybean	Asian rust
Phyllosticta citricarpa	citrus	black spot
Phytophthora capsici	cucurbit, pepper, chili etc	damping off, leaf blight, fruit rot
Phytophthora infestans	potato/tomato	late blight
Phytophthora porri	leek	white tip
Pseudoperonospora humuli	hops	downy mildew
Pyrenopeziza brassicae	oilseed rape	light leaf spot
Pyrenophora teres	barley	net blotch
Pyrenophora tritici-repentis	wheat	tan spot
Ramularia areola	cotton	Ramularia blight
Sclerotinia homoeocarpa	turf, various	dollar spot
Septoria glycines	soybean	brown spot
Septoria lycopersici	tomatoes	Septoria leaf spot
Setosphaeria turcica	maize	Northern leaf blight
Sphaerotheca macularis	strawberry, various	powdery mildew
Sphaerotheca mors-uvae	raspberry, black currants	powdery mildew
Spilocea oleagina	olives	leaf spot
Stemphylium vesicarium	asparagus	purple spot
Venturia carpophila	stone fruits, almonds	scab
Venturia cerasi	cherry	scab
Venturia nashicola	Chinese pear	scab
Venturia pirina	pear	scab
Wilsonomyces carpophilus (*Ascospora beijerinckii*)	cherries, almonds, apricots, etc	shot hole and canker
** 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. Yellow marking indicates pathogens, which were added to this update of the Pathogen Risk List in 2019.

Pathogen	Crop	Disease
Alternaria helianthi	sunflower	leaf blight
Botryosphaeria obtusa	grapes	ESCA
Cochliobolus carbonum, Bipolaris zeicola	corn	Northern leaf spot
Cochliobolus miyabeanus	rice	brown spot
Cronartium ribicola	currants	currant rust
Diaporthe helianthi	sunflower	stem canker
Diplocarpon mespili	quince and hawthorn	leaf blight and fruit spot
Eutypa lata	grapes	ESCA
Fusarium spp.	various	Fusarioses
Gloeodes pomigena	apples	sooty blotch
Gnomonia erythrostoma	cherries	cherry leaf scorch
Gnomonia leptostyla	walnuts	walnut leaf blotch
Guignardia bidwellii	grapes	black rot
Gymnosporangium sabinae	pears	pear rust
Helminthosporium solani	potato	silver scurf
Hemileia vastatrix	coffee	rust
Hypomyces rosellus (Dactylium dendroides)	mushrooms	cobweb mould
Kabatiella zeae	corn	eye spot
Parastagonospora nodorum (Stagonospora)	wheat	leaf spot
Leptosphaeria biglobosa	oilseed rape	black leg
Leptosphaeria maculans	oilseed rape	black leg
Leptothyrium pomi	pome fruit	fly speck
Nectria galligena	pome fruit	canker and dry eye rot
Phaeoacremonium aleophilum	grapes	ESCA
Phaeomoniella chlamydospora	grapes	ESCA
Phoma macdonaldii	sunflower	stem disease
Phomopsis viticola	grapes	cane and leaf spot
Phytophthora cactorum	various	damping off, crown rot
Phytophthora fragariae	strawberry	root rot
Phytophthora rubi	strawberry	root rot
Podosphaera leucotricha	pome fruit	powdery mildew
Pseudopezicula tracheiphila (Pseudopeziza)	grapes	red fire disease
Puccinia sorghi	corn	common rust
Puccinia spp.	wheat / barley, various	rusts
Pythium spp.	various	damping off
Rhizoctonia spp.	various	foot and root rot
Rhynchosporium commune (secalis)	barley	scald
Sclerotinia sclerotiorum	various	white mold
Sclerotium spp.	various	blight
Septoria piricola	pears	leaf spot
Sphaerulina oryzina	rice	narrow brown leaf spot
Taphrina deformans	peaches, almonds	leaf curl
Tilletia spp.	cereals	bunts
Tranzschelia spp.	stonefruits and nuts	rust
Uromyces spp.	various	rust
Ustilago 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. *Pyrenophora* spp. *Ustilago* spp.) soil-borne pathogens (e.g. *Phytophthora* spp.) rust fungi *Rhizoctonia* spp.	*Rhynchosporium commune* *Zymoseptoria tritici* *Oculimacula* spp.	*Blumeria graminis* *Botrytis cinerea* *Penicillium* spp. *Pyricularia oryzae* *Venturia inaequalis* *Pseudocercospora fijiensis*

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). Details can be found in the article written by KH Kuck, "Fungicide Resistance Management in a New Regulatory Environment", in the Proceedings of the Reinhardsbrunn 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. *Pyrenophora* sp. *Ustilago* sp.) soil-borne pathogens (e.g. *Phytophthora* sp.) rust fungi *Rhizoctonia sp.* *Fusarium* sp. *S. sclerotiorum*	*E. necator* *G. fujikuori* *Oculimacula* sp. *R. commune* *P. teres* *Z. tritici* *S. homoeocarpa* *Monilinia* sp. *Cercospora* sp. *P. infestans*	*B. graminis* *B. cinerea* *P. viticola* *P. oryzae* *V. inaequalis* *P. fijiensis*	