Version 3 – February 2018

List of cases of resistance to plant protection products detected in France

Background

The management of resistance to PPPs is a major challenge for plant protection because it contributes to limiting ineffective or remedial treatments and therefore to implementing the French “Plan Ecophyto” on the reduction of pesticide use. Optimal resistance management requires the integration of multiple information (*e.g.* resistance dynamics, the mechanisms involved, the frequency of resistant pests in the area concerned, etc.). It must take into account the specificities of each case of resistance to advise relevant and effective management strategies. However, this information is not always readily accessible. It may be included in complex scientific articles, be part of unpublished “private” information, etc… thus not always being available with sufficient precision or speed.

The lists proposed by R4P display our current knowledge on the cases of PPP resistance detected and published in France. They aim at reaching a more sustainable use of the PPPs by stakeholders by allowing to optimise their recommendations. The sensitivity of pests to PPPs should indeed be considered a common good, and managed accordingly.

Methods

Resistance case lists have been compiled from several sources:

- Experimental data produced by INRA and Anses laboratories (see also the compilation of technical reports on this website) or private laboratories.
- French or foreign literature, scientific or extension literature

Each case presented consist of one “tryptic” (pest / PPP mode of action / crop) for which biological sensitivity assays have proven the occurrence of resistance (*i.e.* at least one resistant individual has been demonstrated as resistant using a relevant procedure). **Suspicions of resistance not validated by appropriate sensitivity assays are not included in the lists.**

The resistance cases listed in these documents concern only France, mainly metropolitan France. A few cases detected in the French overseas departments and territories are also mentioned. The lists may not be comprehensive for these cases, due to a lack of reliable documentary sources. **Similar cases detected in countries other than France are not listed.**

A member of R4P serving as a referent expert is associated to each case listed, as well as relevant publications, preferably in French. The complete references of the publications, as well as the royalty-free files, can be consulted on the "Documentation" section of the R4P website.

Last, the lists display the resistance cases towards fungicides, insecticides, acaricides and herbicides, either for active substances currently registered and in use in France (List I) or for active substances formerly registered in France (List II).

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Legends

Column	Description
Section "Fungicide/Insecticide/Acaricide/Herbicide"	
Mode of action	Biochemical mode of action of the active substance or group of active substances concerned by resistance, as formulated in R4P classification.
Target site	Biochemical target (target protein) of the active substance or group of active substances concerned by resistance. *NB: For more details on targets and modes of action, please refer to the Universal classification of PPPs proposed by R4P on this website.*
R4P group	Code corresponding to the active substance or group of active substances concerned by resistance in R4P Universal classification of PPPs.
Group other than R4P	Code corresponding to the active substance or group of active substances concerned by resistance, in the FRAC (http://www.frac.info/), IRAC (http://www.irac-online.org/), HRAC (http://www.hracglobal.com/), WSSA (http://wssa.net/) or according to Fourouzesh et al. (Weed Research 55:334-358).
Group abbreviation	Common abbreviation for chemical class proposed by R4P.
Chemical class (R4P or other)	Name of the chemical class to which the active substance, or group of active substances, concerned by resistance belongs. Detailed chemical classification is available on this website (R4P universal classification).
Active ingredients	Active substance(s) concerned by resistance, in the laboratory or in the field. Unlisted active ingredients might be concerned by the resistance, especially within the same mode of action. Where a large number of substances are involved, additional information may be provided. Positive and negative cross resistance are detailed in the R4P universal pesticide classification on this website.
Section "Pathogen/Insect/Mite/Weed"	
Pest/Disease	The vernacular name of the pest or the disease concerned by the resistance.
Scientific name	The Latin binomial name of the pest concerned by the resistance.
EPPO code	Universal (acronymic) code of the pest assigned by EPPO (https://gd.eppo.int/).
Crop	Crop concerned by the case of resistance. Some crops may be grouped together (e.g."cereals") for generalist pests. HTV: Herbicide Tolerant Variety.
Status of resistance	"+" indicates that field resistance (partial or total loss of field efficacy of the PPP used under optimal conditions) is possible. It depends in particular on the frequency of resistant individuals in local populations. "(+)" indicates "biological resistance" for which a loss of efficacy has possibly been observed in laboratory assays but not (yet) in the field .
Comments	Comment indicating prevalence (*i.e.* the proportion of plots affected by resistance) and/or frequency of resistance (i.e. the proportion of resistant individuals in populations), depending on the state of knowledge. Information on the geographical location of the resistance case can be detailed when the distribution is not homogeneous, or when resistance is emerging. ARA: Auvergne-Rhône-Alpes; BFC: Bourgogne-Franche-Comté; BZH: Bretagne; COR: Corse; CVL: Centre-Val de Loire; GES: Grand Est; HDF: Hauts de France; IDF:

	Ile de France; NAQ: Nouvelle Aquitaine; NOR: Normandie; OCC: Occitanie; PAC: Provence-Alpes-Côtes d'Azur; PDL: Pays de Loire. Information on the cost of resistance can be added, for resistance cases accompanied by a lower competitiveness of resistant individuals, which can lead to a reduction in the dynamics of resistance evolution. Finally, various additional information (in particular on cross resistances) can be added.
Resistance intensity	For fungicides lists. Estimation of the resistance factor of the resistant individuals: LR: low intensity resistance MR: medium intensity resistance HR: high intensity resistance.
Resistance mechanism	TSR: Target Site Resistance (+ mutation if known). NTSR: Non Target Site Resistance (+ details if known). *For more information on PPP resistance mechanisms, see R4P (2016) Trends in Plant Science.* Unknown: resistance mechanism non elucidated.
First occurrence in France	Collection date of the oldest sample where the resistance case was detected. May be approximate for "ancient" resistances.
Section "Information"	
Contact	Person who can provide more information on the case of resistance.
References	References describing the case of resistance in France (dynamics, mechanism, phenotype etc...). May include publications about the same resistance case out of France to provide additional information (especially on the resistance mechanism).
Update	Date of update of the information concerning the resistance case.

Acknowledgements
R4P warmly thanks Pierre Leroux, Christian Gauvrit, Robert Delorme and Annie Micoud for their extensive participation in completing these lists, and Evelyne Martin for her valuable assistance in managing the bibliographic database.

Readers are invited to indicate any errors or omissions in these lists at: contact-r4p@inra.fr

Fungicide								Pathogen								Information		
Mode of action	Target site	R4P group	FRAC group 1	FRAC group 2	Group abbreviation	R4P chemical class	Active ingredients	Common name	Scientific name	EPPO code	Crop	Status of resistance	Comments	Resistance intensity	Resistance mechanism	First occurrence in France	Contact person	References	Update
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Benzamides, Nicotinamides, Pyrazoles	fluopyram, boscalid, all pyrazoles	Grey mould	*Botrytis cinerea*	BOTRCI	Grapevine	(+)	Presence in all vineyards but at low frequency. Uncomplete cross-resistance between AIs, depending on mutation	LR to HR	TSR (> 10 mutations on SDH genes) + NTSR efflux (MDR)	2007	INRAE Grignon - AS Walker	Leroux et al, 2002; Kreschtmer et al, 2009 ; Leroux et al, 2010; Lalève et al, 2014a ; Lalève et al, 2014b	29/06/20
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Benzamides, Nicotinamides, Pyrazoles	fluopyram, boscalid, all pyrazoles	Grey mould	*Botrytis cinerea*	BOTRCI	Strawberry	(+) but in mixture	Presence in numerous production areas with a regular frequency of resistance from medium to high. Uncomplete cross-resistance between AIs, depending on mutation	LR to HR	TSR (> 10 mutations on SDH genes) + NTSR efflux (MDR)	2011	INRAE Grignon - AS Walker	Bardet et Walker, 2012	29/06/20
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Nicotinamides	boscalid	Powdery mildew	*Erysiphe necator*	UNCINE	Grapevine	(+)	Low frequency resistance, detected in several vineyards including Bordeaux, Languedoc-Roussillon, Burgundy and Gers. Boscalid most affected, uncomplete cross-resistance	LR to HR	TSR; SdhB-H242Y/R SdhC G169D	2014	INRAE Grignon - AS Walker	Note commune Vigne 2020	29/06/20
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Nicotinamides	boscalid	Eyespot	*Oculimacula acuformis*	PSDCHA	Cereals	(+)	Presence in most cereal regions but at low frequency.	LR	NTSR efflux (MDR)	2001	Anses Lyon - B. Barrès, F. Rémuson	Leroux et al, 2013	30/11/17
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Nicotinamides	boscalid	Eyespot	*Oculimacula yallundae*	PSDCHE	Cereals	(+)	Presence in most cereal regions but at very low frequency.	LR	NTSR efflux (MDR)	2001	Anses Lyon - B. Barrès, F. Rémuson	Leroux et al, 2013	30/11/17
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Pyrazoles, Nicotinamides	bixafen, fluxapyroxad, ɔvindiflupyr boscalid	Net blotch	*Pyrenophora teres*	PYRNTE	Barley	(+) but in mixture	Presence in most grain regions. High resistance frequencies (mean stabilized around 70% ; some plots with 100%) but spatial heterogeneity. The plots with the highest presence of resistance are found particularly in the East and North.	LR to HR	TSR (> 10 mutations on SDH genes; C-G79R dominant)	2012	INRAE Grignon - AS Walker	Note commune Céréales 2020; Rapport Anses 2016; Rehfus et al, 2016	29/06/20
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Nicotinamides, Pyrazoles	boscalid, all pyrazoles	Ramularia leaf spot	*Ramularia collo-cygni*	RAMUCC	Barley	+	Resistance detected in many cereal regions; mean frequency around 20% for the two dominant alleles.	HR	TSR C-H146R and C-H153R	2017	INRAE Grignon - A. S. Walker	Note commune céréales 2020	29/06/20
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Pyrazoles, Nicotinamides, Benzamides	bixafen, fluxapyroxad, ɪthiopyrad boscalid	White rot	*Sclerotinia sclerotiorum*	SCLESC	Oilseedrap e	+	Presence in the majority of production regions, particularly in the Centre and Ile de France, to a lesser extent in the neighbouring departments. Intraplot frequency difficult to estimate but possibly high locally. Occurrence stabilizing, over the last few years. Boscalid most affected, uncomplete cross-resistance	LR to HR	TSR (> 10 mutations on SDH genes; D-H132R and C-H146R dominant)	2008	INRAE Grignon - AS Walker	Walker et al, 2015; Penaud et Walker, 2016; Penaud et al, 2018	29/06/20
Mitochondrial respiration and energy supply	Mitochondrial complex II (SDH)	A2a	C2	7	SDHI	Oxathiin-carboxamides, Pyrazoles, Nicotinamides, Furan-carboxamides	carboxin, boscalid, sedaxane, fluxapyroxad, fenfuram, thifluzamide	Loose smut	*Ustilago nuda*	USTINH	Barley	(+)	Presence in all cereal regions, with locally variable resistance frequency. Uncomplete spectrum of cross-resistance	LR to HR	TSR; 4 mutations on SDHB, C and D	1983	INRAE Grignon - AS Walker	Note commune céréales 2016; Leroux, 1986 ; Leroux and Berthier, 1988	29/06/20
Mitochondrial respiration and energy supply	Mitochondrial complex II	A2a	C2	7	SDHI	Pyrazoles, Nicotinamides, Benzamides	bixafen, fluxapyroxad, benzovindiflupyr, fluopyram, boscalid	Septoria leaf blotch	*Zymoseptoria tritici*	SEPTTR	Wheat	(+)	Detected in 36% of the tested populations throughout France in 2019 (mostly Brittany and Normandy). C-H132R found for the first time in 2018 and generally at low frequency. Other Sdh mutation can be at low to moderate frequency. RNLC detected in 77% of plots (mainly in the northern half of France), with an average frequency of 27% in 2019.	LR	TSR (> 10 mutations on SDH genes; C-T79N and C-N86S dominant; C-H132R rare) + NTSR efflux (MDR)	2012 (2008 MDR)	INRAE Grignon - AS Walker	Note commune Céréales 2020; Leroux et Walker, 2009a; Leroux et Walker, 2011; Omrane et al, 2018; Garnault et al, 2019	29/06/20
Mitochondrial respiration and energy supply	Complex III: fixation at Qi site (*cytb* gene)	A3b	C4	21	QiI	Azole sulfonamides	ɔfamid amisulbrom	Downy mildew	*Plasmopara viticola*	PLASVI	Grapevine	+	NTSR is present in all vineyards, with medium to high frequency. Low to high frequency of TSR detected in several vineyards.	HR	NTSR (AOX) + TSR (cytb E203-DE-V204 dominant; cytb E203-VE-V204 and cytb-L201S rare)	2013 (NTSR) + 2016 (TSR	Anses Lyon - B. Barrès, F. Rémuson	Micoud et al, 2015; note commune vigne 2020; Fontaine et al, 2019	29/06/20
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin pyraclostrobin trifloxystrobin kresoxim-methyl	Grey mould	*Botrytis cinerea*	BOTRCI	Strawberry	(+)	Resistance present in many regions, regularly high frequency, in relation to the treatment history.	HR	TSR cytb-G143A	2012	INRAE Grignon	Bardet et Walker, 2012; Leroux et al, 2010	30/11/17
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C4	11	QoI-P	Strobilurins	azoxystrobin, picoxystrobin pyraclostrobin kresoxim-methyl, trifloxystrobin fluoxastrobin	Cercospora leaf spot	*Cercospora beticola*	CERCBE	Sugar beet	+	Resistance present in all sugar regions, usually at high frequency	HR	TSR cytb-G143A	Unknown, probably early 2010s	INRAE Grignon - A. S. Walker	Report of RECIFE project (2020)	29/06/20
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin, picoxystrobin pyraclostrobin kresoxim-methyl, trifloxystrobin fluoxastrobin	Powdery mildew	*Erysiphe graminis*	ERYSGR	Cereals	+	Resistance present mainly in the northern half of France, generally high frequency	HR	TSR cytb-G143A	2002	INRAE Grignon - A. S. Walker	Walker et Leroux, 2003 ; Walker et al, 2004 ; Walker et al, 2006 ; Walker et al, 2011a	30/11/17
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin, pyraclostrobin kresoxim-methyl, trifloxystrobin	Powdery mildew	*Erysiphe necator*	UNCINE	Grapevine	+	Resistance present in all vineyards, high frequency.	HR	TSR cytb-G143A	2008	INRAE Grignon - A. S. Walker	Dufour et al, 2011; Dufour et al, 2009 ; Mauranx and Steva, 2012; Note commune vigne 2020	29/06/20
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin, picoxystrobin pyraclostrobin trifloxystrobin dimoxystrobin fluoxastrobin	Pink snow mould	*Microdochium majus*	MICDMA	Wheat	+	Resistance present in all cereal regions, usually high frequency.	HR	TSR cytb-G143A, NTSR (AOX) + unknown mechanism	before 2007	INRAE Grignon - A. S. Walker	Walker et al, 2009; Leroux et Walker, 2009b	29/06/20

Fungicide								Pathogen									Information		
Mode of action	Target site	R4P group	FRAC group 1	FRAC group 2	Group abbreviation	R4P chemical class	Active ingredients	Common name	Scientific name	EPPO code	Crop	Status of resistance	Comments	Resistance intensity	Resistance mechanism	First occurrence in France	Contact person	References	Update
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin, picoxystrobin pyraclostrobin trifloxystrobin dimoxystrobin fluoxastrobin	Pink snow mould	*Microdochium nivale*	MONGNI	Wheat	+	Resistance present in all cereal regions, usually moderate frequency.	HR	TSR cytb-G143A	before 2007	INRAE Grignon - A. S. Walker	Walker et al, 2009; Leroux et Walker, 2009b	30/11/17
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins and others	azoxystrobin pyraclostrobin famoxadone fenamidone	Downy mildew	*Plasmopara viticola*	PLASVI	Grapevine	+	Resistance present in all vineyards, high frequency.	HR	TSR cytb-G143A	2003	INRAE Grignon - A. S. Walker	Magnien et al, 2003; Magnien et al, 2009 ; Corio-Costet al, 2006; Chen et al, 2007; Delmas et al, 2017	30/11/17
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin, picoxystrobin pyraclostrobin kresoxim-methyl, trifloxystrobin fluoxastrobin	Net blotch	*Pyrenophora teres*	PYRNTE	Barley	+	Resistance present in all cereal regions, frequency stabilized around 30% (20-50% in 2019).	MR to HR	TSR cytb-F129L	2005	INRAE Grignon - A. S. Walker	Maumene et al, 2009; note commune 2020; Rehfus et al, 2016	29/06/20
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	picoxystrobin pyraclostrobin trifloxystrobin	Tan spot	*Pyrenophora tritici-repentis*	PYRNTR	Wheat	(+)	Situation not well informed. Probably rare, mostly northeast.	MR to HR	TSR cytb-G143A and cytb-F129L	2008	INRAE Grignon - A. S. Walker	note commune céréales 2020	29/06/20
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	pyraclostrobin	Ramularia	*Ramularia collo-cygni*	RAMUCC	Barley	+	Resistance present in all cereal regions, usually high frequency.	HR	TSR cytb-G143A	2007	INRAE Grignon - A. S. Walker	note commune céréales 2020	29/06/20
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin, picoxystrobin pyraclostrobin trifloxystrobin fluoxastrobin	Scald	*Rynchosporium commune*	RHYNCSE	Barley	(+)	Rare resistance, detected pontually (notably Pas de Calais)	HR	TSR cytb-G143A	2008	INRAE Grignon - A. S. Walker	note commune céréales 2016	30/11/17
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	kresoxim methyl trifloxystrobine	Apple scab	*Venturia inaequalis*	VENTIN	Apple	+	Resistance present in orchards of the North-East to the South-West, generally high frequency.	HR	TSR cytb-G143A + NTSR	2004	Anses Lyon - B. Barrès, F. Rémuson	Fontaine et al, 2006 ; Remuson et al, 2007 ; Fontaine et al, 2009	30/11/17
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (*cytb* gene), binding proximal to heme bl	A5	C3	11	QoI-P	Strobilurins	azoxystrobin, picoxystrobin pyraclostrobin trifloxystrobin fluoxastrobin	Septoria leaf blotch	*Zymoseptoria tritici*	SEPTTR	Wheat	+	Resistance present in all cereal regions, usually high frequency (>90% in average).	HR	TSR cytb-G143A + NTSR efflux (MDR)	2003 (2008 MDR)	INRAE Grignon - A. S. Walker	Leroux et al, 2006a,b ; Leroux et al, 2007 ; Leroux et walker, 2009a ; Leroux et Walker, 2011; Garnault et al, 2019	29/06/20
Mitochondrial respiration and energy supply	Complex III: cytohrome bc1 (ubiquinol reductase) at Qo site, binding distal to heme bl	A6	C8	45	QioI	Triazolopyrimidines	ametoctradin	Downy mildew	*Plasmopara viticola*	PLASVI	Grapevine	+ (NTSR)	NTSR is present in all vineyards, with medium to high frequency. Low-frequency TSR detected in several vineyards (low in Champagne and higher in South-West).	HR	NTSR (AOX) + TSR cytb-S34L	2014	Anses Lyon - B. Barrès, F. Rémuson	Micoud et al, 2015; note commune vigne 2020; Fehr et al, 2015; Fontaine et al, 2019	29/06/20
Mitochondrial respiration and energy supply	Oxydative phosphorylation	A10a	C5	29	OPUC	Dinitroanilines	fluazinam	Downy mildew	*Phytophthora infestans*	PHYTIN	Potato	+	Resistance present in about 80% of the populations tested in 2017, from Brittany, Champagne, Picardie, Nord-Pas de Calais.	MR	unknown	2017	INRAE Grignon - A-S Walker	Gaucher et al, 2018	30/11/17
Carbohydrate metabolism	cellulose-synthase	C1a	H5	40	CESI	Carboxamides (CAA)	dimethomorph benthiavalicarb, iprovalicarb, valifenalate mandipropamid	Downy mildew	*Plasmopara viticola*	PLASVI	Grapevine	+	Resistance present in all vineyards, medium to high frequency.	HR	TSR Ces-G1105S	2003	Anses Lyon - B. Barrès, F. Rémuson	Magnien et al, 2009 ; Blum et al, 2010	30/11/17
Sterol biosynthesis in membranes	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Imidazoles,Triazoles, Triazolinethiones	difénoconazole, tétraconazole	Cercospora leaf spot	*Cercospora beticola*	CERCBE	Sugar beet	+	Resistance present in all sugar regions, usually at high frequency. Resistance affects azoles differently. First caracterized in 2019 but probably selected in the early 2010s.	LR to HR	TSR (several mutations in cyp51) + NTSR (cyp51 overexpression)	2019	INRAE Grignon - A. S. Walker	Report of RECIFE project (2020)	29/06/20
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Imidazoles, Triazoles, Triazolinethiones	prochloraz cyproconazole, epoxiconazole, flutriafol, metconazole, propiconazole, tebuconazole, tetraconazole prothioconazole	Powdery mildew	*Erysiphe graminis f. sp. hordei*	ERYSGR	Barley	+ some DMIs	Resistance present in all regions of powdery mildew, high frequency.	LR to HR	TSR cyp51-Y137F +/- cyp51-K147Q	1990s	INRAE Grignon - A. S. Walker	Walker et al, 2004; Walker et al, 2006 ; Delye et al, 1998 ; Wyand and Brown, 2005	30/11/17
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Imidazoles,Triazoles, Triazolinethiones	prochloraz cyproconazole, epoxiconazole, flutriafol, metconazole, propiconazole, tebuconazole, tetraconazole prothioconazole	Powdery mildew	*Erysiphe graminis f. sp. tritici*	ERYSGR	Wheat	+ some DMIs	Resistance present in all regions of powdery mildew, high frequency.	LR to HR	TSR cyp51-Y137F	1990s	INRAE Grignon - A. S. Walker	Walker and Leroux, 2003 ; Walker et al, 2004 ; Walker et al, 2006 ; Delye et al, 1998 ; Wyand and Brown, 2005	30/11/17
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Triazoles	cyproconazole, difenoconazole, fenbuconazole, myclobutanil, penconazole, tebuconazole, tetraconazole, triadimenol	Powdery mildew	*Erysiphe necator*	UNCINE	Grapevine	+	Resistance present in all vineyards, high frequency but stabilizing.	MR	TSR several mutations in cyp51 including Y136F + overexpression	1989	INRAE Grignon - A. S. Walker	Delye et al, 1997 ; Corio-Costet et al, 2003 ; Dufour et al, 2009 ; Dufour et al, 2011 ; Rallos et Baudoin, 2016	29/06/20

Fungicide								Pathogen								Information		
Mode of action	Target site	R4P group	FRAC group 1	FRAC group 2	Group abbreviation	R4P chemical class	Active ingredients	Common name	Scientific name	EPPO code	Crop	Status of resistance	Comments	Resistance intensity	Resistance mechanism	First occurrence in France	Contact person	References	Update
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Imidazoles, Triazoles, Triazolinethiones	prochloraz epoxiconazole, propiconazole, tebuconazole, tetraconazole prothioconazole	Eyespot	*Oculimacula acuformis*	PSDCHA	Cereals	+ but not prothioconazole	Resistance present in all cereal regions, high frequency	MR to HR	TSR?	1990 (2001 efflux)	Anses Lyon - B. Barrès, F. Rémuson	Leroux et al, 2006c ; Albertini et al, 2003; Durand et al, 2015 ; Leroux et Walker, 2009a ; Leroux et al, 2013	30/11/17
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Imidazoles, Triazoles, Triazolinethiones	prochloraz epoxiconazole, propiconazole, tebuconazole, tetraconazole prothioconazole	Eyespot	*Oculimacula yallundae*	PSDCHE	Cereals	+ but not prothioconazole	Resistance present in all cereal regions, high frequency	MR to HR	TSR? + NTSR efflux (MDR)	1991 (2001 efflux)	Anses Lyon - B. Barrès, F. Rémuson	Leroux et al, 2006c ; Albertini et al, 2003; Durand et al, 2015 ; Leroux et Walker, 2009a ; Leroux et al, 2013	30/11/17
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Triazoles	myclobutanil penconazole	Powdery mildew	*Podosphaera aphanis*	PODOAP	Strawberry	+	Resistance present in several regions, moderate frequency.	LR to HR	TSR?	2008	INRAE Bordeaux - M. F. Coriot-Costet	Sombardier et al, 2010	30/11/17
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Imidazoles, Triazoles, Triazolinethiones	prochloraz cyproconazole, difenoconazole, epoxiconazole, metconazole, propiconazole, tebuconazole prothioconazole	Net blotch	*Pyrenophora teres*	PYRNTE	Barley	+	Resistance present in cereal regions, prothioconazole seems less affected. Frequency unknown	LR to HR	TSR (mutations non described	1990s	INRAE Grignon - A. S. Walker	Note commune céréales 2020; Mair et al, 2016	29/06/20
Sterol biosynthesis in membranes	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Triazolinethiones	prothioconazole	Tan spot	*Ramularia collo-cygni*	RAMUCC	Barley	+	Resistance present in cereal regions, low to high frequency.	HR	TSR (several combinations of mutations in cyp51 including I381T, I384L, Y459C or Y460H)	2016	INRAE Grignon - A. S. Walker	Forte émergence en Allemagne, accompagné échecs efficacité	29/06/20
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Triazoles Triazolinethiones	prochloraz cyproconazole, epoxiconazole, propiconazole, tebuconazole prothioconazole	Scald	*Rynchosporium commune*	RYNCSP	Barley	+ some triazoles	Resistance present in all cereal regions, no recent information	MR	TSR	1990s	INRAE Grignon - A. S. Walker	Robbertse et al, 2001; Brunner et al, 2016	06/07/20
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Triazoles	many	Apple scab	*Venturia inaequalis*	VENTIN	Apple	+ many DMIs	Resistance present in the Centre, Midy-Pyrénées, Pays de Loire, PACA, Rhône Alpes, in all populations tested. High frequency.	MR to HR	TSR?	90s	Anses Lyon - B. Barrès, F. Rémuson	Parisi et al, 1991 ; Parisi et al, 1994 ; Remuson et al, 2003 ; Remuson et al, 2015 ; Gao et al, 2009	30/11/17
Sterol metabolism	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)	E2	G1	3	SBI-DM or DMI (class I)	Imidazoles, Triazoles, Triazolinethiones	prochloraz bromuconazole, cyproconazole, difenoconazole, epoxiconazole, flutriafol, metconazole, propiconazole, tebuconazole, tetraconazole prothioconazole	Septoria leaf blotch	*Zymoseptoria tritici*	SEPTTR	Wheat	+	Resistance present in all cereal regions, high frequency. Resistance affects azoles differently, according to the frequency of genotypes in populations. Uncomplete patterns of cross-resistance. In 2019, TriHR strains (high RF towards several azoles) found in 89% of the populations tests, mean frequency 46%. MDR strains found in 77% of the populations tested, mean frequency 27%.	LR to HR	TSR (combinations of many mutations in cyp51 + overexpression) + NTSR (efflux MDR, at least 3 genotypes)	before 90s (2008 efflux)	INRAE Grignon - A. S. Walker	Leroux et al, 2006a,b ; Leroux et al, 2007 ; Leroux et Walker, 2009a ; Leroux et Walker, 2011; Omrane et al, 2015; Note commune céréales 2020; Garnault et al, 2019	29/06/20
Sterol metabolism	Δ14-reductase and Δ8→Δ7 isomerase in sterol biosynthesis (*erg24, erg2*)	E3	G2	5	SBI-IR (class II)	Amines	fenpropimorph enpropidin spiroxamine	Powdery mildew	*Erysiphe graminis*	ERYSGR	Cereals	?	Resistance present in cereal regions with powdery mildew, variable frequency.	MR	unknown	1990s	INRAE Grignon - A. S. Walker	Walker et al, 2004; Walker et al, 2006 ; Genet et Jaworska, 2009	30/11/17
Sterol metabolism	3-keto reductase, C4-demethylation	E4	G3	13	SBI-KR (class III)	oxyanilides Pyrazolinones	fenhexamid fenpyrazamine	Grey mould	*Botrytis cinerea*	BOTRCI	Grapevine	(+)	Resistance present in all vineyards, low frequency. Occasionally more frequent in the Loire Valley, including Muscadet. Low resistance cost characterized, which can help to limit the frequency of this resistance.	MR to HR	TSR + NTSR efflux (MDR)	2003	INRAE Grignon - A. S. Walker	Albertini et al, 2004 ; Fillinger et al, 2008 ; Grosman et al, 2009 ; Leroux et al, 2002; Kreschtmer et al, 2009 ; Leroux et al, 2010 ; Leroux and Walker, 2013 ; Debieu et al, 2013; Billard et al, 2012 ; Tanaka et al, 2012	30/11/17
Sterol metabolism	3-keto reductase, C4-demethylation	E4	G3	13	SBI-KR (class III)	oxyanilides Pyrazolinones	fenhexamid fenpyrazamine	Grey mould	*Botrytis cinerea*	BOTRCI	Strawberry	(+) but in association	Resistance present in all production areas, low to high frequency, in relation to the treatment history.	HR	TSR	<2012	INRAE Grignon - A. S. Walker	Bardet et Walker, 2012	30/11/17
Sterol metabolism	3-keto reductase, C4-demethylation	E5	G4	13	SBI-KR (class III)	oxyanilides Pyrazolinones	fenhexamid fenpyrazamine	Grey mould	*Botrytis cinerea*	BOTRCI	Tomato	(+)	Resistance detected from population in the Champagne area at low frequency but possibly present in other regions	HR	TSR	2006	INRAE Grignon - A. S. Walker	Walker et al, 2015	08/07/20
Sterol metabolism	3-keto reductase, C4-demethylation	E4	G3	13	SBI-KR (class III)	oxyanilides Pyrazolinones	fenhexamid fenpyrazamine	Grey mould	*Botrytis pseudocinerea*	BOTRPS	Grapevine	(+)	Resistance present in all vineyards, frequency less than 10% and mainly spring observations.	HR	TSR + NTSR detoxication (natural resistance)	1997	INRAE Grignon - A. S. Walker	Leroux et al, 2002 ; Walker et al, 2011b	30/11/17
Amino acids and protein synthesis	unknown	F6b	-	27	-	Cyanoacétamides-oximes	cymoxanil	Downy mildew	*Plasmopara viticola*	PLASVI	Grapevine	(+) but associated	Resistance detected in all vineyards, at moderate frequency. Few recent data.	HR	unknown	1990s	Anses Lyon - B. Barrès, F. Rémuson	Genet et Vincent, 1999	30/11/17
Biosynthesis of nucleic acids	RNA polymerase I	G3	A1	4	RNAPI	Phenylamides (PA)	métalaxyl, oxadixyl	Downy mildew	*Bremia lactucae*	BREMLA	Lettuce	+	Presence in many regions including Southern and Eastern France. Old data.	HR	TSR ARN PolI	1987	INRAE Grignon - A-S Walker	Leroux et al, 1988; Maisonneuve et al, 1989	30/11/17

Fungicide								Pathogen									Information		
Mode of action	Target site	R4P group	FRAC group 1	FRAC group 2	Group abbreviation	R4P chemical class	Active ingredients	Common name	Scientific name	EPPO code	Crop	Status of resistance	Comments	Resistance intensity	Resistance mechanism	First occurrence in France	Contact person	References	Update
Biosynthesis of nucleic acids	RNA polymerase I	G3	A1	4	RNAPI	Phenylamides (PA)	metalaxyl-M (= mefenoxam)	Late blight	*Plasmopara halstedii*	PLASHA	Sunflower	+	Resistance detected in many areas, medium to high frequency.	HR	TSR ARN PolI	90s	INRAE Grignon - A. S. Walker	Albourie et al, 1998	30/11/17
Biosynthesis of nucleic acids	RNA polymerase I	G3	A1	4	RNAPI	Phenylamides (PA)	benalaxyl, belenaxyl-M (=kiralaxil), metalaxyl-M (= mefenoxam)	Potato blight	*Phytophthora infestans*	PHYTIN	Potato	+	Resistance present in all production regions, high frequency.	HR	TSR ARN PolI	80s	INRAE Grignon - A. S. Walker	Detourné et al, 2004; Gisi and Cohen, 1996	30/11/17
Biosynthesis of nucleic acids	RNA polymerase I	G3	A1	4	RNAPI	Phenylamides (PA)	benalaxyl, belenaxyl-M (=kiralaxil), metalaxyl-M (= mefenoxam)	Downy mildew	*Plasmopara viticola*	PLASVI	Grapevine	+	Resistance detected in all vineyards, high frequency.	HR	TSR ARN PolI	1980	Anses Lyon - B. Barrès, F. Rémuson	Leroux and Clerjeau, 1985	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Grey mould	*Botrytis cinerea*	BOTRCI	Grapevine	+	Resistance present in all vineyards, low and declining frequency in absence of treatment for a long time.	HR	TSR tub2-E198A	1980s	INRAE Grignon - A. S. Walker	Leroux et al, 2002; Walker et al, 2013	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B2	1	-	Thiophanates (BMC)	thiophanate-methyl	Grey mould	*Botrytis cinerea*	BOTRCI	Tomato	+	Resistance detected from populations in the Champagne area at high frequency ; possibly present in other regions	HR	TSR tub2-E198A	2006	INRAE Grignon - A. S. Walker	Walker et al, 2015	08/07/20
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B3	1	-	Thiophanates (BMC)	thiophanate-methyl	Grey mould	*Botrytis cinerea*	BOTRCI	Grapevine	(+)	Resistance detected in some vineyards, rare.	HR	TSR tub2-E198A	1980s	INRAE Grignon - A. S. Walker	Leroux et al, 2002; Walker et al, 2013	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Ascochyta blight	*Dydimella pinodes*	MYCOPI	Pea	?	Old data. Unknown but high frequency in described populations	HR	TSR	1990s	INRAE Grignon - AS Walker	Molinero et al, 1993	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Ascochyta blight	*Ascochyta pisi*	MYCOPI	Pea	?	Old data. Unknown but high frequency in described populations	HR	TSR	1990s	INRAE Grignon - AS Walker	Molinero et al, 1993	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Black point	*Fusarium avenaceum*	GIBBAV	Cereals	(+)	Resistance detected in several regions, low frequency. Old data.	HR	TSR?	2000s	INRAE Grignon - A. S. Walker	Leroux and Walker, 2009b	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Almond canker	*Fusicoccum amygdali*	FUSCAM	Almond	(+)	Resistance observed in Corsica. Uninformed frequency.	HR	TSR tub2-E198K	2016	Anses Lyon - B. Barrès, F. Rémuson	Rapport Anses 2016	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Pink snow mould	*Microdochium majus*	MICDMA	Cereals	+	Resistance detected in all cereal regions, medium to high frequency.	HR	TSR tub2-E198A	80s	INRAE Grignon - A. S. Walker	Leroux and Walker, 2009b	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Pink snow mould	*Microdochium nivale*	MONGNI	Cereals	+	Resistance detected in all cereal regions, medium to high frequency.	HR	TSR tub2-E198A	80s	INRAE Grignon - A. S. Walker	Leroux and Walker, 2009b	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Brown rot	*Monilinia fructicola*	MONIFC	Peach, Apricot, Plum	+	Resistance detected in all production regions, high frequency.	HR	TSR	2001	Anses Lyon - B. Barrès, F. Rémuson	Report Anses 2010; Ma et al, 2003	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Thiophanates (BMC)	thiophanate-methyl	Apple bark canker	*Neofabraea alba*	PEZIAL	Apple	?	Resistance present in the south-east, medium frequency.	HR	unknown	2010	Anses Lyon - B. Barrès, F. Rémuson	Internal report Anses 2011	30/11/17
Cell division and cytoskeleton	Delocalisation of spectrin-like proteins	K6	B5	43	-	Benzamides	fluopicolid	Downy mildew	*Plasmopara viticola*	PLASVI	Grapevine	(+)	Resistance detected in some plots in Champagne, Bordeaux, South-Western France, Charentes. A priori low frequency but progression; detection in new vineyards in 2019	HR	unknown	2016	Anses Lyon - B. Barrès, F. Rémuson	note commune vigne 2020	29/06/20
Cell division and cytoskeleton	Actin - unkown target	K5	-	U8	-	Phenylketones	metrafenone pyriofenone	Powdery mildew	*Erysiphe graminis*	ERYSGR	Cereals	(+)	Resistance detected in several cereal regions, low frequency	LR to MR	unknown	2009	INRAE Grignon - A. S. Walker	Note commune céréales 2016 ; Opalski et al, 2006	30/11/17
Cell division and cytoskeleton	Actin - unkown target	K5	-	U8	-	Phenylketones	metrafenone pyriofenone	Powdery mildew	*Erysiphe necator*	UNCINE	Grapevine	(+)	Resistance detected in several vineyards (South-East, Val de Loire, Beaujolais); rare.	MR	unknown	>2010	INRAE Grignon - A. S. Walker	Note commune vigne 2016	29/06/20
Cellular signalling	MAP/Histidine-Kinase in osmotic signal transduction (*os2, HOG1*)	M1c	E2	12	-	Phenylpyrroles (PP)	fludioxonil	Blackspot	*Alternaria brassicicola*	ALTEBI	Cabbage	?	Resistance detected in several regions. Old data.	?	TSR	<2004	INRAE Grignon - A. S. Walker	Iacomi-Valisescu et al, 2004; Avenot et al, 2005	30/11/17
Cellular signalling	MAP/Histidine-Kinase in osmotic signal transduction (*os2, HOG1*)	M1c	E2	12	-	Phenylpyrroles (PP)	fludioxonil	Grey mould	*Botrytis cinerea*	BOTRCI	Grapevine	(+)	MDR detected in all vineyards, mainly in Champagne and Burgundy. Very variable frequency.	LR	NTSR efflux (MDR)	1993	INRAE Grignon - A. S. Walker	Leroux et al, 2002; Kreschtmer et al, 2009 ; Leroux et al, 2010	06/07/20
Cellular signalling	Regulation of cell cycle - miochondrial kinase?	M2	D1	9	-	Anilinopyrimidines (AP)	pyrimethanil, cyprodinil, mepanipyrim	Grey mould	*Botrytis cinerea*	BOTRCI	Grapevine	(+)	Resistance present in all vineyards, variable frequency, in relation to the history of treatment. A cost associated with this resistance can help limiting its evolution. Efficacy affected in the 80s.	MR	TSR? + NTSR efflux (MDR)	1994	INRAE Grignon - A. S. Walker	Leroux et al, 2002 ; Kreschtmer et al, 2009 ; Walker et al, 2013	30/11/17
Cellular signalling	Regulation of cell cycle - miochondrial kinase?	M2	D1	9	-	Anilinopyrimidines (AP)	pyrimethanil, cyprodinil, mepanipyrim	Grey mould	*Botrytis cinerea*	BOTRCI	Tomato	(+)	Resistance detected in some Champagne populations at low frequency; possibly present in other areas	MR	TSR	2006	INRAE Grignon - A. S. Walker	Walker et al, 2015	08/07/20
Cellular signalling	Regulation of cell cycle - miochondrial kinase?	M2	D1	9	-	Anilinopyrimidines (AP)	cyprodinil	Powdery mildew	*Erysiphe graminis*	ERYSGR	Cereals	+ partial	Resistance detected in many cereal regions; frequency poorly reported.	MR	TSR?	1990s	INRAE Grignon - A. S. Walker	Rougerie et al, 2000; Walker et al, 2006 ; Genet et Jaworska, 2009	30/11/17
Cellular signalling	Regulation of cell cycle - miochondrial kinase?	M2	D1	9	-	Anilinopyrimidines (AP)	cyprodinil	Eyespot	*Oculimacula acuformis*	PSDCHA	Cereals	(+)	Resistance detected in many cereal regions in most plots; moderate frequency ; old data	LR to HR	TSR?	1999	INRAE Grignon - A. S. Walker	Leroux et al, 2006c ; Leroux et al, 2013	30/11/17
Cellular signalling	Regulation of cell cycle - miochondrial kinase?	M2	D1	9	-	Anilinopyrimidines (AP)	cyprodinil	Eyespot	*Oculimacula yallundae*	PSDCHE	Cereals	(+)	Resistance detected in many cereal regions in most plots; moderate frequency ; old data	LR to HR	TSR? + RNLC efflux (MDR)	1999	INRAE Grignon - A. S. Walker	Leroux et al, 2006c ; Leroux et al, 2013	30/11/17
Cellular signalling	Regulation of cell cycle - miochondrial kinase?	M2	D1	9	-	Anilinopyrimidines (AP)	pyrimethanil, cyprodinil	Apple scab	*Venturia inaequalis*	VENTIN	Apple	(+)	Resistance detected in Lorraine, Midi-Pyrénnées, Pays de Loire, Rhônes-Alpes, Provence, in most of the plots sampled. Frequency can be high locally.	MR	TSR?	2000s (2005)	Anses Lyon - B. Barrès, F. Rémuson	Micoud et Remuson, 2006	30/11/17

Fungicide								Pathogen									Information		
Mode of action	Target site	R4P group	FRAC group 1	FRAC group 2	Group abbreviation	R4P chemical class	Active ingredients	Common name	Scientific name	EPPO code	Crop	Status of resistance	Comments	Resistance intensity	Resistance mechanism	First occurrence in France	Contact person	References	Update
Cellular signalling	Signal transduction (mechanism unknown)	M4	E1	13	-	Aza-naphthalenes (AZN)	quinoxyfen proquinazid	Powdery mildew	*Erysiphe graminis*	ERYSGR	Cereals	+	Resistance mainly present in Champagne and border regions. Low to moderate frequency.	LR to HR	unknown	2003	INRAE Grignon - A. S. Walker	Walker et Leroux, 2003 ; Walker et al, 2004; Walker et al, 2006; Genet et Jaworska, 2009	30/11/17
Cellular signalling	Signal transduction (mechanism unknown)	M4	E1	13	-	Aza-naphthalenes (AZN)	quinoxyfen proquinazid	Powdery mildew	*Erysiphe necator*	UNCINE	Grapevine	+	Resistance present in all vineyards. Variable frequency, depending on the selection pressure. The cost of this resistance helps to reduce the frequency of the disease in the absence of treatment.	LR to HR	unknown	early 2000s	INRAE Grignon - A. S. Walker	Genet et Jaworska, 2009	30/11/17
Inducers of host plant responses	Stimulation and interference with phosphonate metabolism	S2	U	33	-	Phosphites and phosphonates	fosétyl d'aluminium	Little leaf decline of pine	*Phytophthora cinnamoni*	PHYTCN	Lawson's cypress (Chamaecy paris lawsoniana)	+	Old data. Unknown but probably rare (a few nurseries in Normandy)	LR	unknown	1985	INRAE Grignon - A. S. Walker	Leroux et al, 1986; Vegh et al, 1985	30/11/17
Multisites	Several	W2	M1	-	MSI	Copper-based mineral substances	copper	Bacterial blight	*Xanthomonas arboricola juglandis*	XANTJU	Walnut	+	Resistance present in Rhône Alpes and Périgord. Moderate to high frequency.	MR to HR	unknown	2011	Anses Lyon - B. Barrès, F. Rémuson	Report Anses 2015	30/11/17