

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 It may be included in complex scientific articles, be part of unpublished “private” information, etc...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). **Suspicious 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).

Legends

Column	Description
Section "Fungicide/Insecticide/Acaricide/Herbicide"	
<i>Mode of action</i>	Biochemical mode of action of the active substance or group of active substances concerned by resistance, as formulated in R4P classification.
<i>Target site</i>	Biochemical target (target protein) of the active substance or group of active substances concerned by resistance. <i>NB: For more details on targets and modes of action, please refer to the Universal classification of PPPs proposed by R4P on this website.</i>
<i>R4P group</i>	Code corresponding to the active substance or group of active substances concerned by resistance in R4P Universal classification of PPPs.
<i>Group other than R4P</i>	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).
<i>Group abbreviation</i>	Common abbreviation for chemical class proposed by R4P.
<i>Chemical class (R4P or other)</i>	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).
<i>Active ingredients</i>	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"	
<i>Pest/Disease</i>	The vernacular name of the pest or the disease concerned by the resistance.
<i>Scientific name</i>	The Latin binomial name of the pest concerned by the resistance.
<i>EPPO code</i>	Universal (acronymic) code of the pest assigned by EPPO (https://gd.eppo.int/).
<i>Crop</i>	Crop concerned by the case of resistance. Some crops may be grouped together (e. g. "cereals") for generalist pests. HTV: Herbicide Tolerant Variety.
<i>Status of resistance</i>	"+" 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 .
<i>Comments</i>	Comment indicating prevalence (<i>i.e.</i> the proportion of plots affected by resistance) and/or frequency of resistance (<i>i.e.</i> 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:

	<p>Ile de France; NAQ: Nouvelle Aquitaine; NOR: Normandie; OCC: Occitanie; PAC: Provence-Alpes-Côtes d'Azur; PDL: Pays de Loire.</p> <p>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.</p> <p>Finally, various additional information (in particular on cross resistances) can be added.</p>
<i>Resistance intensity</i>	<p>For fungicides lists.</p> <p>Estimation of the resistance factor of the resistant individuals:</p> <p>LR: low intensity resistance MR: medium intensity resistance HR: high intensity resistance.</p>
<i>Resistance mechanism</i>	<p>TSR: Target Site Resistance (+ mutation if known). NTSR: Non Target Site Resistance (+ details if known). <i>For more information on PPP resistance mechanisms, see R4P (2016) Trends in Plant Science.</i></p> <p>Unknown: resistance mechanism non elucidated.</p>
<i>First occurrence in France</i>	Collection date of the oldest sample where the resistance case was detected. May be approximate for "ancient" resistances.
Section "Information"	
<i>Contact</i>	Person who can provide more information on the case of resistance.
<i>References</i>	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).
<i>Update</i>	Date of update of the information concerning the resistance case.

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

et de Recherches sur
les Résistances
aux Pesticides

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	EPO 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	A2a	C2	7	SDHI	Oxathiin-carboxamides	oxycarboxin	White rust	<i>Puccinia horiana</i>	PUCCHN	Chrysanthemum	(+)	Distribution unknown. No recent sampling.	HR	unknown	1970s	INRAE Grignon - AS Walker	Grouet et al, 1981	30/11/17
Mitochondrial respiration and energy supply	Complex III: fixation at Qo site (<i>cytb</i> gene), binding proximal to heme b _L	A5	C3	11	QoI-P	Strobilurins	many	Grey mould	<i>Botrytis cinerea</i>	BOTRCI	Grapevine	(+) no specific treatment	Resistance present in all vineyards, high frequency. Unintentional selection by treatments for other foliar diseases.	HR	TSR cytb-G143A	before 2007	INRAE Grignon - AS Walker	Leroux et al, 2010	30/11/17
Mitochondrial respiration and energy supply	Mitochondrial complex V or ATP synthase	A9	C6	30	ATPSI	Organotin	fentine-hydroxyde	Cercospora leaf spot	<i>Cercospora beticola</i>	CERCBE	Sugar beet	(+)	Present in most sugar areas at low to moderate frequency in 2020, despite AI removal.	HR	unknown	Detected 2019 but probably selected 1980s	INRAE Grignon - AS Walker	Report of RECIFE project (2020)	29/06/20
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Benzimidazoles (BMC)	carbendazim	Leaf spot	<i>Aschochyta spp</i>	ASCOFA	Pea	+	No recent data	HR	TSR	1993	INRAE Grignon - A. S. Walker	Allard et al, 1993	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Benzimidazoles (BMC)	carbendazim	Dry rot	<i>Gibberella pulicaris</i>	GIBBPU	Potato	+	No recent data	HR	TSR	80s	INRAE Grignon - A. S. Walker	Daami-Remadi et al, 2006	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Benzimidazoles (BMC)	carbendazim	Eyespot	<i>Oculimacula aciformis</i>	PSDCHA	Cereals	+	Resistance present in all cereal regions, medium to high frequency.	HR	TSR tub2-E198A	80s	INRAE Grignon - A. S. Walker	Leroux et al, 2006c ; Albertini et al, 1999	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Benzimidazoles (BMC)	carbendazim	Eyespot	<i>Oculimacula yallundae</i>	PSDCHE	Cereals	+	Resistance present in all cereal regions, medium to high frequency.	HR	TSR tub2-E198A	80s	INRAE Grignon - A. S. Walker	Leroux et al, 2006c ; Albertini et al, 1999	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Benzimidazoles (BMC)	carbendazim	White rot	<i>Sclerotinia sclerotiorum</i>	SCLESC	Oilseedrape	+	Resistance present in all production regions, high frequency.	HR	TSR tub2-E198A	2000	INRAE Grignon - A. S. Walker	Kaczmar et al, 2000; Penaud et al, 2003; Penaud et Walker, 2016	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Benzimidazoles (BMC)	carbendazim	Apple scab	<i>Venturia inaequalis</i>	VENTIN	Apple	+	Resistance present in all regions, high frequency.	HR	TSR	1970s	Anses Lyon - B. Barrès, F. Rémuson	Martin et al, 1981	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2b	B1	1	-	Benzimidazoles (BMC)	carbendazim	Septoria leaf blotch	<i>Zymoseptoria tritici</i>	SEPTTR	Wheat	+	Resistance present in all cereal regions, high frequency	HR	TSR tub2-E198A	before 90s	INRAE Grignon - A. S. Walker	Leroux et al, 2006a,b	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2c	B2	10	-	N-phenyl-carbamates	diethofencarb	Grey mould	<i>Botrytis cinerea</i>	BOTRCI	Grapevine	+	Resistance present in all vineyards, rare, decreasing, since the abandonment of the diethofencarb (cost of resistance demonstrated).	HR	TSR tub2-F200Y	1990s	INRAE Grignon - A. S. Walker	Leroux et al, 2002; Walker et al, 2013	30/11/17
Cell division and cytoskeleton	Microtubules - beta-tubulin	K2c	B2	10	-	N-phenyl-carbamates	diethofencarb	Grey mould	<i>Botrytis cinerea</i>	BOTRCI	Grapevine	+	Resistance detected from populations in the Champagne area at moderate frequency ; possibly present in other regions	HR	TSR tub2-F200Y	2006	INRAE Grignon - A. S. Walker	Walker et al, 2015	08/07/20
Cellular signalling	MAP/Histidine-Kinase in osmotic signal transduction (<i>os1, Daf11</i>)	M1b	E3	2	-	Dicarboximides	iprodione, procymidone, vinchlorzolin	Blackspot	<i>Alternaria brassicae</i>	ALTEBI	Cabbage	?	Resistance detected in several regions. Old data.	MR	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 (<i>os1, Daf11</i>)	M1b	E4	2	-	Dicarboximides	iprodione, procymidone, vinchlorzolin	Grey mould	<i>Botrytis cinerea</i>	BOTRCI	Tomato	+	Resistance detected in some Champagne populations at high frequency; possibly present in other areas	MR	TSR	2006	INRAE Grignon - A. S. Walker	Walker et al, 2015	08/07/20
Cellular signalling	MAP/Histidine-Kinase in osmotic signal transduction (<i>os1, Daf11</i>)	M1b	E5	2	-	Dicarboximides	iprodione, procymidone, vinchlorzolin	Grey mould	<i>Botrytis cinerea</i>	BOTRCI	Grapevine	+	Resistance detected in all vineyards, at low frequency, except occasionally in relation to the treatment program. The cost associated with this resistance probably contributes to limiting its evolution.	MR	TSR + NTSR efflux (MDR)	early 1980s	INRAE Grignon - A. S. Walker	Leroux et al, 2002; Kreschmer et al, 2009 ; Leroux et al, 2010 ; Leroux and Walker, 2013	30/11/17
Cellular signalling	Polys et osmorégulation - histidine kinase?	M1b	E3	2	-	Dicarboximides	iprodione, procymidone, vinchlorzolin	White rot	<i>Sclerotinia sclerotiorum</i>	SCLESC	Oilseedrape	(+)	Resistance present in all production regions, at low frequency, decreasing (probable cost of resistance).	MR	TSR	début 80s	INRAE Grignon - A. S. Walker	Penaud et al, 2003 ; Penaud et Walker, 2016	30/11/17
Cellular signalling	Polys et osmorégulation - histidine kinase?	M1c	E2	12	-	Phenylpyrroles (PP)	fludioxonil	White rot	<i>Sclerotinia sclerotiorum</i>	SCLESC	Oilseedrape	(+)	Rare resistance, detected punctually.	HR	TSR	2005	INRAE Grignon - A. S. Walker	Penaud et al, 2003 ; Penaud et Walker, 2016	30/11/17