



FRAC
LIST OF PLANT PATHOGENIC
ORGANISMS RESISTANT TO DISEASE
CONTROL AGENTS

Revised January 2013

Important notes

The scope of the list.

The FRAC codes used in this document refer to those used in the FRAC Code List. The entries are listed by their Mode of Action code, with the Chemical Group Codes and Group Names also being given for reference. *For more information please refer to the latest edition of the FRAC Code list.*

This list is extensive in identifying those plant pathogens that have shown some form of resistance to the modes of action given and to the respective chemical groups. Where a FRAC Code is not listed, no resistance has been reported.

Entries have generally been selected as the first confirmed, published, case of resistance of the particular mode of action against the pathogen listed. Subsequent references for the same mode of action and host-pathogen combination are only included if the information is considered by FRAC to be of special merit e.g. information on the molecular mode of resistance. Inclusion of cases of a known pathogen but a new host e.g. *Botrytis cinerea* are considered on their merits. Similarly, references reporting a known case but in a different geographical region are also considered on merit and may not be included.

Take care in using this list.

Care must be taken in using the information because:

1. Inclusion of a pathogen in this list only demonstrates that it can become resistant. It does not indicate that pathogen populations in specific geographical areas or locations are resistant. Seek local advice for specific localities. Information may also be found at the FRAC web page for specific chemical Working Groups. See www.frac.info
2. Resistance in plant pathogens can take many forms and it is important to realise the differences when consulting this list. The 'Remarks' column gives guidance on the form of resistance found and can be interpreted as:

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Laboratory mutation / selection: Indicates that the resistance has been selected for using various techniques including mutation by UV light, or chemical mutagenesis. Such research illustrates that resistance can happen and can provide information on the resistance mechanism, but is not a reliable indicator of the probability that resistance will happen when the chemical is used in the field.

Field trial: Indicates that resistance has been found in limited field trials. Very often such trials use application schedules that are different to commercial practice and/or are designed to pressurise pathogen populations into becoming resistant in an attempt to quantify the resistance risk. Such trials show that resistance can be generated but do not give reliable indications that resistance will occur if products are used as recommended.

Field: Indicates that resistant isolates have been found in commercially treated fields. This does not mean that the resistance was always extensive enough to cause complete disease control failure, but does indicate a need for active resistance management.

3. For pathogens capable of infecting several host genera / species e.g. *Botrytis cinerea*, the list does not include reference to all known crops. For such pathogens it is reasonable to assume that if resistance is known, all areas of use are at risk and resistance management strategies should be used.

Cross – resistance between chemicals in a particular group.

Resistance and cross-resistance between molecules in a particular group is not always absolute due to different activity spectra shown by group members. Be careful when making assumptions about cross-resistance patterns and if in any doubt refer to FRAC or the manufacturer.

A note on taxonomy

This list has been compiled using the taxonomy in use at the time the report was made. In some cases organisms have been reclassified since the original report and names have changed. Where names have changed recently, users of this list are advised to search using the old name as well as the new one.

Further guidance

Please see information published by FRAC and contained in the FRAC Monographs, available for download from the FRAC webpage www.frac.info

Updates

FRAC welcomes suggestions for inclusion in this list; please send information, including full Journal reference, to the Secretary. Note that only cases of confirmed resistance will be included, supported by a published report from an accredited source. Reports of rumours of resistance or unverified reports will not be included. The decision on inclusion rests with FRAC. New entries in the 2013 edition of the list are marked in [blue](#).

A note on mercury:

Mercury was a traditional seed treatment for cereals. It is no longer used and, as such, does not appear in the FRAC list of fungicides. Resistance did develop to it in *Pyrenophora avenae* on oats, Noble *et al.* (1966), and for *Pyrenophora graminea* on barley, Clark (1985).

Mode of Action Code and Target Site	Group Name	FRAC Group Code
A: NUCLEIC ACID SYNTHESIS		
A1: RNA polymerase I	PA Fungicides Phenylamides	4
A2: Adenosine deaminase	Hydroxy – (2-amino) pyrimidines	8
A3: DNA/RNA synthesis (proposed)	Heteroaromatics	32
A4: DNA topoisomerase type II (gyrase)	Carboxylic acids	31
B: MITOSIS AND CELL DIVISION		
B1: β -tubulin assembly in mitosis	MBC fungicides, Methyl Benzimidazole Carbamates	1
B2: β -tubulin assembly in mitosis	N-phenylcarbamates	10
B3: β -tubulin assembly in mitosis	Benzamides	22
B4: Cell division (proposed)	Phenylureas	20
B5: Delocalisation of spectrin like proteins	Benzamides	43
C: RESPIRATION		
C1: Complex I, NADH oxidoreductase	Pyrimidinamines	39
C2: Complex II, succinate-dehydrogenase	SDHI fungicides	7
C3: Complex III, cytochrome bc1 (ubiquinol oxidase at Qo site (cyt b gene)	QoI fungicides, Quinone Outside Inhibitors	11
C4: Complex III, cytochrome bc1 (ubiquinone reductase) at Qi site	QiI fungicides (Quinone Inside Inhibitors)	21
C5: Uncouplers of oxidative phosphorylation	-	29
C6: Inhibitors of oxidative phosphorylation. ATP synthase	Organo tin compounds	30
C7: ATP production (proposed)	Thiophene carboxamides	38
C8: Complex III, cytochrome bc1 (ubiquinone reductase) at Qx (unknown) site	Triazolo-pyrimidylamine	45

Mode of Action Code and Target Site	Group Name	FRAC Group Code
D: AMINO ACIDS AND PROTEIN SYNTHESIS		
D1: Methionine biosynthesis (proposed) (<i>cgs gene</i>)	AP fungicides. Anilinopyrimidines	9
D2: Protein synthesis	Enopyranuronic acid antibiotic	23
D3: Protein synthesis	Hexapyranosyl antibiotic	24
D4: Protein synthesis	Glucopyranosyl antibiotic	25
D5: Protein synthesis	Tetracycline antibiotic	41
E: SIGNAL TRANSDUCTION		
E1: Signal transduction (mechanism unknown)	Aza-naphthalenes	13
E2: MAP/Histidine-kinase in osmotic signal transduction (<i>os-2, HOG1</i>)	PP fungicides. Phenylpyrroles	12
E3: MAP/Histidine-kinase in osmotic signal transduction (<i>os-1, Daf1</i>)	Dicarboximides	2
F: LIPIDS AND MEMBRANE SYNTHESIS		
F1	Formerly dicarboximides	
F2: Phospholipid biosynthesis, methyl transferase	Phosphoro thiolates and dithiolanes	6
F3: Lipid peroxidation (proposed)	AH fungicides (Aromatic Hydrocarbons)(chlorophenyls, nitroanilines and heteroaromatics)	14
F4: Cell membrane permeability, fatty acids (proposed)	Carbamates	28
F5: Moved to H5	CAA fungicides. Carboxylic Acid Amides	40
F6: Microbial disrupters of pathogen cell membranes	<i>Bacillus subtilis</i> and the fungicidal lipopeptides produced	44
F7: Membrane disruption (proposed)	Plant extract	46

Mode of Action Code and Target Site	Group Name	FRAC Group Code
G: STEROL BIOSYNTHESIS IN MEMBRANES		
G1: C14 demethylase in sterol biosynthesis (<i>erg11/cyp51</i>)	DMI fungicides. DeMethylation Inhibitors. SBI Class 1	3
G2: Δ^{14} reductase and $\Delta^8 - \Delta^7$ isomerase in sterol-biosynthesis (<i>erg24, erg2</i>)	Amines ('morpholines'). SBI class II	5
G3: 3-keto reductase, C4-demethylation (<i>erg27</i>)	Hydroxyanilides. SBI class III	17
G4: Squalene epoxidase in sterol biosynthesis (<i>erg1</i>)	SBI class IV	18
H: CELL WALL BIOSYNTHESIS		
H3: Trehalase and inositol biosynthesis	Glucopyranosyl antibiotic	26
H4: Chitin synthase	Polyoxins	19
H5: Cellulose synthase	CAA fungicides. Carboxylic Acid Amides	40
I: MELANIN SYNTHESIS IN CELL WALL		
I1: Reductase in melanin biosynthesis	MBI-R Melanin Biosynthesis Inhibitors – Reductase	16.1
I2: Dehydratase in melanin biosynthesis	MBI-D Melanin Biosynthesis Inhibitors – Dehydratase	16.2
P: HOST PLANT DEFENCE INDUCTION		
P1: Salicylic acid pathway	Benzo-thiadiazole BTH	P
P2: Benzisothiazole	Benzisothiazole	P
P3: Thiadiazole-carboxamide	Thiadiazole-carboxamide	P
P4:	Natural compound	P

Mode of Action Code and Target Site	Group Name	FRAC Group Code
UNKNOWN MODE OF ACTION		
Unknown	Cyanoacetamide-oxime	27
Unknown	Phosphonates	33
Unknown	Phthalamic acids	34
Unknown	Benzotriazines	35
Unknown	Benzene-sulfonamides	36
Unknown	Pyridazinones	37
Unknown	Thiocarbamate	42
Microtubule disruption (proposed)	Thiazole carboxamide	U5
Unknown	Phenyl-acetamide	U6
Actin disruption (proposed)	Benzophenone	U8
Cell membrane disruption (proposed)	Guanidines (dodine)	U12
Unknown	Thiazolidine	U13
Unknown	Pyrimidinone-hydrazones	U14
NOT CLASSIFIED		
Unknown	Diverse	NC
MULTI-SITE CONTACT ACTIVITY		
Multi-site contact activity	Inorganic (copper)	M1
	Inorganic (sulphur)	M2
	Dithiocarbamates and relatives	M3
	Phthalimides	M4
	Chloronitriles (phthalonitriles)	M5
	Sulfamides	M6
	Guanidines	M7
	Triazines	M8
	Quinones	M9

LIST OF RESISTANT PATHOGENS

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
A NUCLEIC ACID SYNTHESIS						
A1	4	PA Fungicides (PhenylAmides). RNA polymerase 1				
		<i>Bremia lactucae</i>	Downy mildew	Lettuce	Crute <i>et al.</i> 1987; Crute & Harrison 1988	field, genetics
		<i>Peronospora destructor</i>	Downy mildew	Onion	Wright 2004	-
		<i>Peronospora hyoscyami</i> (syn. <i>P tabacina</i>)	Blue mold	Tobacco	Bruck <i>et al.</i> 1982	field
		<i>Peronospora tabacina</i>	Blue mold	Tobacco	Bruck <i>et al.</i> 1981	field
		<i>Peronospora viciae</i>	Downy mildew	Pea	Falloon <i>et al.</i> 2000	field
		<i>Phytophthora cactorum</i>	Crown rot / leather rot	Strawberry	Bal <i>et al.</i> 1987	field
				American ginseng	Hill & Hausbeck 2008	field
		<i>Phytophthora capsici</i>	Stem rot	Lima bean pods	Davey <i>et al.</i> 2008	field
		<i>Phytophthora cinnamomi</i>	Root rot	Avocado	Darvas & Becker 1984	field
		<i>Phytophthora citricola</i>	Rot / die back		Joseph & Coffey 1984	<i>in-vitro</i> mutation
		<i>Phytophthora citrophthora</i>	Collar rot / foot rots		Serrhini <i>et al.</i> 1985	<i>in-vitro</i>
		<i>Phytophthora citrophthora</i>	Collar rot / foot rots		Angeles Diaz Borrás & Vila Aguila 1988	<i>in -vitro</i>
		<i>Phytophthora erythroseptica</i>	Pink rot	Potato	Lambert & Salas 1994	field
					Taylor <i>et al.</i> 2002	field

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Phytophthora infestans</i>	Late blight	Potato	Davidse <i>et al.</i> 1981 Hartill <i>et al.</i> 1983 Davidse <i>et al.</i> 1983	field field field
		<i>Phytophthora infestans</i>	Late blight	Poroporo	Hartill <i>et al.</i> 1983	field
		<i>Phytophthora megasperma f.sp. glycinea</i>	Root rot	Soybean in-vitro	Lamboy & Paxton 1992	laboratory selection
		<i>Phytophthora megasperma f.sp. medicaginis</i>	Root rot	Lucerne	Davidse 1981	laboratory selection
		<i>Phytophthora melonis</i>	Foot rot	Cucurbits	Wu <i>et al.</i> 2011	field (China)
		<i>Phytophthora nicotianae</i>	Root rot	Ornamentals	Hu <i>et al.</i> 2008	field
		<i>Phytophthora palmivora</i>	Root rot	-	Lucas <i>et al.</i> 1990	laboratory induction
		<i>Phytophthora parasitica</i>	Downy mildew	Periwinkle	Ferrin & Kabashima 1991	field / laboratory
		<i>Phytophthora parasitica var. nicotianae</i>	Black shank	Tobacco	Shew 1985	laboratory
		<i>Phytophthora porri</i>	Downy mildew	Leek	Locke <i>et al.</i> 1997	field
		<i>Phytophthora sojae</i> (syn. <i>P. megasperma</i>)	Stem / root rot	Soybean	Bhat <i>et al.</i> 1993	laboratory
		<i>Phytophthora</i> sp.	Root rot	African violet	Romano & Edgington 1985	field
		<i>Plasmopara halstedii</i>	Downy mildew	Sunflower	Albourie <i>et al.</i> 1998	field
		<i>Plasmopara obducens</i>	Downy mildew	Impatiens (Busy lizzy)	FRAC 2011 FRAG UK 2011	
		<i>Plasmopara viticola</i>	Downy mildew	Grapevine	Staub & Sozzi 1981 Bosshard & Schuepp 1983 Leroux & Clerjeau 1985	field field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Pseudoperonospora cubensis</i>	Downy mildew	Cucumber	Reuveni <i>et al.</i> 1980	field
		<i>Pythium aphanidermatum</i>	Damping off	-	Sanders & Soika 1988	field
		<i>Pythium aphanidermatum</i>		Not specified / creeping bent grass	Sanders <i>et al.</i> 1990	<i>in-vitro</i> mutation / field
		<i>Pythium aphanidermatum</i>	Damping off	Ornamentals	Moorman <i>et al.</i> 2002	field
		<i>Pythium cylindrosporium</i>	Damping off	Ornamentals	Moorman <i>et al.</i> 2002	field
		<i>Pythium dissotocum</i>	Root rot	Carrot	White <i>et al.</i> 1988	field
		<i>Pythium dissotocum</i>	Root rot	Ornamentals	Moorman <i>et al.</i> 2002	field
		<i>Pythium heterothallicum</i>	Damping off	Ornamentals	Moorman <i>et al.</i> 2002	field
		<i>Pythium irregular</i>	Damping off	Ornamentals	Moorman <i>et al.</i> 2002	field
		<i>Pythium splendens</i>	Damping off	Ornamentals	Moorman <i>et al.</i> 2002	field
		<i>Pythium spp.</i>	Cavity spot various	Carrot Potato	White <i>et al.</i> 1988 Porter <i>et al.</i> 2009	field / laboratory field
		<i>Pythium ultimum</i>	Watery wound rot	Potato	Taylor <i>et al.</i> 2002	field
		<i>Pythium ultimum</i>	Damping off	Ornamentals	Moorman <i>et al.</i> 2002	field
A2	8	Hydroxy (2 amino) pyrimidines: Adenosine-deaminase				
		<i>Erysiphe graminis</i> f.sp. <i>hordei</i>	Powdery mildew	Barley	Hollomon 1978	field
		<i>Sphaerotheca fuliginea</i>	Powdery mildew	Cucurbits	Schepers 1984 O'Brien <i>et al.</i> 1988	field
A3	32	Heteroaromatics DNA / RNA synthesis (proposed) No resistance recorded				

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
A4	31	Carboxylic acids				
		<i>Erwinia amylovora</i>	Fire blight	Pear	Manulis <i>et al.</i> 2003, Kleitman <i>et al.</i> 2005	field survey
B MITOSIS AND CELL DIVISION						
B1	1	MBC fungicides (Methyl Benzimidazole Carbamates)				
		<i>Alternaria alternata</i>	Alternaria rot	Citrus	Sitton & Pierson 1982	field
		<i>Ascochyta byj</i>	Ascochyta blight	Vegetables	Steekelenburg 1973	laboratory
		<i>Ascochyta pinodes</i>	Leaf spot	Pea	Molinero <i>et al.</i> 1993	laboratory
		<i>Ascochyta pisi</i>	Leaf spot	Pea	Molinero <i>et al.</i> 1993	laboratory
		<i>Aspergillus nidulans</i>	Bearings rot	Banana	Hasti & Georgopoulos 1971	laboratory
		<i>Botryodiplodia theobromae</i>	Botryodiplodia rot	Fruits (Mango)	Spalding 1982	Laboratory
		<i>Botrytis allii</i>	Neck rot	Onion	Viljanen-Rollinson <i>et al.</i> 2007	Field (New Zealand)
		<i>Botrytis cinerea</i>	Grey mold	cyclamen	Bollen & Scholten 1971	laboratory
		<i>Botrytis cinerea</i>	Chocolate spot	Beans	Harrison J G 1984	field
		<i>Botrytis cinerea</i>	Grey rot	Grapes / Vines	Ehrenhardt <i>et al.</i> 1973 Leroux <i>et al.</i> 1982 Elad <i>et al.</i> 1988	field cross resistance to phenylcarbamates, Group 10
		<i>Botrytis cinerea</i>	Grey mould	Lisianthus	Elad <i>et al.</i> 2008	field

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		<i>Botrytis elliptica</i>	Grey rot	Lily	Chastagner & Riley 1987 Hsiang & Chastagner 1990	field
		<i>Botrytis squamosa</i>	Leaf blight	Alliacea	Presly & Maude 1982	laboratory
		<i>Botrytis tulipae</i>	Fire blight	Tulip	Chastagner & Riley 1987	field
		<i>Ceratocystis ulmi</i>	Dutch elm disease	Elm	Brasier & Gibbs 1975	laboratory
		<i>Cercospora apii</i>	Early blight	Celery	Berger 1973	field
		<i>Cercospora arachidicola</i>	Leafspot	Peanut	Clarke <i>et al.</i> 1974; Littrell 1974	field
		<i>Cercospora beticola</i>	Leafspot	Sugar beet	Georgopoulos & Dovas 1973	field
		<i>Cercospora musae</i>	Leafspot	Banana	See <i>Mycosphaerella musicola</i>	
		<i>Cercosporidium personatum</i>	Late Leafspot	Peanut	Clarke <i>et al.</i> 1974	field
		<i>Cladobotryum dendroides</i>	Cobweb disease	Mushrooms	McKay <i>et al.</i> 1998	laboratory
		<i>Cladosporium carpophilum</i>	Scab	Peach, Nectarine	Chandler <i>et al.</i> 1978	field
		<i>Cladosporium cladosporioides</i>	Fruit rot	Fruits	Dekker 1972	review
		<i>Cladosporium cucumerinum</i>	Cladosporium	Cucurbits	Dekker 1972	review
		<i>Cladosporium fulvum</i>	Flower rot	Fruits	Staunton 1975	field
		<i>Coccomyces hiemalis</i>	Cherry leaf spot	Cherry	Jones & Ehret 1981	field
		<i>Colletotrichum cereal</i>	Anthracnose	Turfgrass	Wong <i>et al.</i> 2008	field
		<i>Colletotrichum coffeanum</i>	Coffee berry disease	Coffee	Cook & Pereira	field
		<i>Colletotrichum gloeosporioides</i>	Anthracnose	Pome fruit	Spalding 1982	laboratory
		<i>Colletotrichum lindemuthianum</i>	Anthracnose	Bean	Meyer 1976	review

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		<i>Colletotrichum musae</i>	Anthracnose	Banana	Griffiee 1973	field
		<i>Corynespora cassicola</i>	target spot	tomato	Date <i>et al.</i> 2004	field
		<i>Cryptocline cyclaminis</i>	Anthracnose	Cyclamen	Garibaldi <i>et al.</i> 1987	field
		<i>Cylindrocladium scoparium</i>	Stem canker	Eucalyptus <i>Callistemon</i> sp., <i>Pistacia lentiscus</i>	Prest &Poppe 1988 Vitale <i>et al.</i> 2009	field field
		<i>Cylindrocladium scoparium</i>	Stem canker	Eucalyptus	Prest &Poppe 1988	field
		<i>Didymella bryoniae</i>	Gummy stem blight	Cucurbits	Malathrakis & Vakalounakis 1983 Steekelenburg 1987	field
		<i>Didymella lycopersici</i>	Stem rot	Tomato		
		<i>Drechslera oryzae</i>	Brown spot	Rice	Annamali & Lalithakumari 1987	laboratory
		<i>Elsinoë fawcetti</i>	Scab	Citrus	Whiteside 1980a Ieki 1994	field
		<i>Elsinoë veneta</i>	Anthracnose	Raspberry	Munro <i>et al.</i> 1988	field
		<i>Erysiphe cichoracaerum</i>	Powdery mildew	Cucurbits	Abelentsev & Savchenko 1980	field
		<i>Erysiphe graminis</i>	Powdery mildew	Cereals	Vargas 1973	field
		<i>Erysiphe polygoni</i>	Powdery mildew	Cowpeas	Rodriguez & Melendez 1984	field
		<i>Erythronium spp.</i>	Yellow fawn	Lily	Duineveld & Beijersbergen 1975	field
		<i>Fulvia fulva</i> also see <i>Cladosporium fulvum</i>	Leaf mold	Tomato	Miao & Higgins 1986	laboratory
		<i>Fusarium culmorum</i>	Fusariose	Potato / Pink	Seppanen 1983 Hanson <i>et al.</i> 1996	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Fusarium graminearum</i>	Fusarium head blight	Cereals	Chen <i>et al.</i> 2009	Laboratory / mutation study
		<i>Fusarium nivale</i>	Pink snow mold	Wheat	Tanaka <i>et al.</i> 1983	field
		<i>Fusarium oxysporium f. sp. dianthi</i>	Fusariose	Oeillet	Tramier & Bettachini 1974	field
		<i>Fusarium oxysporium f. sp. gladioli</i>	Fusariose	Gladiolus	Magie & Wilfret 1974	field
		<i>Fusarium oxysporium f. sp. lycopersici</i>	Fusariose	Tomato	Thanassouloupoulos <i>et al.</i> 1970	laboratory
		<i>Fusarium oxysporium f. sp. tulipae</i>	Fusariose	Tulip	Valaskova 1983	laboratory
		<i>Fusarium oxysporium f. sp. Melonis</i>	Fusariose	Melon	Bastels-Schooley & MacNeil 1971	laboratory
		<i>Fusarium roseum</i>	Fusariose	Rosa, turf	Smiley & Howard 1976	field
		<i>Fusarium roseum</i> var. <i>sambucinum</i>	Dry rot	Potato	Tivoli <i>et al.</i> 1986	field
		<i>Fusarium solani f. sp. pisi</i>	Fusariose	Solanaceae	Richardson 1973	field, laboratory
		<i>Fusarium sulphureum</i>	dry rot	Potato	Hanson <i>et al.</i> 1996	field
		<i>Fusicladium effusum</i>	Scab	Pecan	Littrell 1977	
		<i>Gibberella fujikuroi</i>	Fusariose	Rice	Ogawa 1988	field
		<i>Gibberella zeae</i>		Rice	Liu <i>et al.</i> 2010	lab analysis
		<i>Gloeosporium spp.</i>	Fruit rot	Apple		
		<i>Glomerella acutata</i>	Storage rot	Apple	Weber & Palm 2010	field isolates
		<i>Guignardia citricarpa</i>	Black spot	Citrus	Herbert & Grech 1985	field
		<i>Helminthosporium solani</i>	Silver scurf	Potato	Geary <i>et al.</i> 2007	field (USA)
		<i>Hypomyces rosellus</i>	Cobweb disease	Mushrooms	Fletcher & Yarham 1976	field

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		<i>Leveillula taurica</i>	Powdery mildew	Tomato	Jones & Thompson 1982	field
		<i>Monilinia cinerea</i>	Brown rot	Rosa	Abelentsev & Golyshin 1973	laboratory
		<i>Monilinia fructicola</i>	Brown rot	Pome fruit	Jones & Ehret 1976	field
		<i>Monilinia fructigena</i>	Brown rot	Pome fruit	Abelentsev & Golyshin 1973	laboratory
		<i>Monilinia laxa</i>	Brown rot	Pome fruit	Ogawa <i>et al.</i> 1981	field
		<i>Mycogone pernicioso</i>	Wet bubble	Mushrooms	Fletcher & Yarham 1976	field
		<i>Mycosphaerella brassicicola</i>	Ring spot	Brassicas		
		<i>Mycosphaerella citri</i>	Greasy spot	Citrus	Whiteside 1980b	field
		<i>Mycosphaerella fijiensis</i>	Black spot	Banana	Stover 1979	field
		<i>Mycosphaerella fragariae</i>	Leaf spot	Strawberry	Remiro & Kimati 1974	field
		<i>Mycosphaerella melonis</i>	Leaf spot / gummy stem blight	Strawberry	Kato <i>et al.</i> 1984	field
		<i>Mycosphaerella musicola</i>	Yellow spot	Banana	Joya C 1982	field
		<i>Neofabraea alba</i>	Storage rot	Apple	Weber & Palm 2010	field isolates
		<i>Neofabraea perennans</i>	Storage rot	Apple	Weber & Palm 2010	field isolates
		<i>Neonectria galligena</i>	Storage rot	Apple	Weber & Palm 2010	field isolates
		<i>Neurospora crassa</i>	Red mold	Bread	Sisler 1971	laboratory
		<i>Oidiopsis taurica</i>	Powdery mildew	Artichoke		
		<i>Oidium begonia</i>	Powdery mildew	Begonia		
		<i>Penicillium brevicompactum</i>			Bollen & Scholten 1971	laboratory

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Penicillium corymbiferum</i>	Rot	Crocus	Bollen & Scholten 1971 Jarvis & Hargreaves 1973	laboratory field
		<i>Penicillium digitatum</i>	Green rot	Citrus / Pome fruit	Wild 1983	field
		<i>Penicillium expansum</i>	Blue mold	Pome fruit / pear	Wicks 1977	field
		<i>Penicillium fructigenum</i>		various	Ida W 1975	field
		<i>Penicillium italicum</i>	Blue rot	Citrus	Muirhead 1974; Yu 1981	field
		<i>Penicillium oxalicum</i>	Stem rot	Cucurbits		
		<i>Penicillium sclerotigenum</i>		Yellow yam	Plumbley <i>et al.</i> 1984	field
		<i>Pestalotiopsis longiseta</i>	Gray blight	Tea	Omatsu <i>et al.</i> 2012	field
		<i>Pezizula alba</i>	Ripe spot	Pome fruits	Bielenin 1986	field
		<i>Phoma clematidina</i>	Wilt	Clematis	*	
		<i>Phoma tracheiphila</i>	Malsecco	Citrus	Gilmenez & Luisi. 1978	field
		<i>Phytophthora citricola</i>	Dieback	Azalea	Ferrin & Kabashima 1991	field / laboratory
		<i>Phomopsis citri</i>	Stem-end rot	Citrus	Spalding 1982	laboratory
		<i>Podosphaera leucotricha</i>	Powdery mildew	Fruit trees	Suta & Radulescu 1986	laboratory
		<i>Pseudocercospora herpotrichoides</i>	Eyespot	Cereals	Griffin <i>et al.</i> 1982	field
		<i>Pyrenopeziza brassicae</i>	Light leaf spot	Oilseed rape	Ilott <i>et al.</i> 1987	laboratory
		<i>Rhynchosporium secalis</i>	Leaf blotch/scald	Barley		
		<i>Rhizoctonia solani</i>	Brown Rhizoctonia	Solanaceae	Martin <i>et al.</i> 1984	laboratory
		<i>Sclerotinia fructicola</i>	Brown rot	Stone fruits	Whan J H 1976	field

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Sclerotinia homeocarpa</i>	Dollar spot	Grass	Cole 1974 Detweiler <i>et al.</i> 1983 Wong S P 2003	field
		<i>Sclerotinia sclerotiorum</i>	Sclerotiniose	Oilseed rape		
		<i>Sclerotium spp.</i>	Stem rot	Alliaceae/Potato/Carrot		
		<i>Septoria apiicola</i>	Leaf spot	Celery		
		<i>Septoria leucanthemi</i>	Leaf spot	Chrysanthemum	Paulus <i>et al.</i> 1976	field
		<i>Septoria tritici</i>	Leaf spot	Cereals	Griffin & Fisher 1985	laboratory
		<i>Sphaerotheca fuliginea</i>	Powdery mildew	Cucurbits	Schroeder & Providenti 1971; Naegler <i>et al.</i> 1977	field
		<i>Sphaerotheca humuli</i>	Powdery mildew	Ornamental flowers	Iida 1975	field
		<i>Sphaerotheca pannosa</i>	Powdery mildew	Rosa / Peach tree	Jarvis & Slingsby 1975	field
		<i>Sporobolomyces roseus</i>	Pink yeast	Rosa (mutation)	Nachmias & Barash 1976	laboratory
		<i>Stagonospora curtisii</i>	Leaf scorch	Ornamental flowers / Narcissus	Saniewska 1985	field
		<i>Talaromyces flavis</i>		Fruits	Katan <i>et al.</i> 1984	laboratory
		<i>Tapesia yallundae</i>	Eyespot	Cereals	see <i>P. herpotrichoides</i>	field
		<i>Tapesia acuformis</i>	Eyespot	Cereals	see <i>P. herpotrichoides</i>	field
		<i>Trichoderma harzianum</i>	Green mold	Soil / Mushrooms	Eastburn & Butler 1986	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Uncinula necator</i> (now <i>Erysiphe necator</i>)	Powdery mildew	Grapes / Vines	Naegler <i>et al.</i> 1977; Pearson 1980 Pearson & Taschenberg 1980	field
		<i>Ustilago hordei</i>	Barley covered smut	Barley	Ben-Yephet Y <i>et al.</i> 1975	laboratory
		<i>Venturia inaequalis</i>	Scab	Pome fruit	Kiebacher & Hoffmann 1976	field
		<i>Venturia nashicola</i>	Scab	Pome fruit	Ishii & Yamaguchi 1981	field
		<i>Venturia pirina</i>	Scab	Pome fruit	Shabi & Ben-Yephet 1976	field
		<i>Verticillium albo-atrum</i>	Verticillium	Pome fruits	Ververke 1983	laboratory
		<i>Verticillium dahlia</i>	Verticillium	Pome fruit / Solanacea	Locke & Thorpe 1976 McHugh & Schreiber 1984	field
		<i>Verticillium fungicola</i>	Verticillium	Mushrooms	Fletcher & Yarham 1976; Samuels & Johnston 1980	field
		<i>Verticillium malthousei</i> (= <i>V. fungicola</i>)	Verticillium	Mushrooms	Lambert & Wuest 1973	field
		<i>Verticillium tricorpus</i>	Wilt	Tomato		

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
B2	10	N-phenyl carbamates: β tubulin assembly in mitosis				
		<i>Botrytis cinerea</i>	Grey mold	Grapevine	Elad <i>et al.</i> 1988 Katan <i>et al.</i> 1989 Elad <i>et al.</i> 1992	cross resistance to phenylcarbamates, Group 10 field field
		<i>Corynespora cassiicola</i>	Target spot	Tomato	Date <i>et al.</i> 2004	field
		<i>Neurospora crassa</i>			Fujimura <i>et al.</i> 1994	resistance mechanism
		<i>Verticillium fungicola</i>	Dry bubble	Mushroom	Bonnen & Hopkins 1997	field isolates
B3	22	Benzamides β tubulin assembly in mitosis No resistance recorded				
B4	20	Phenylureas cell division (proposed)				
		<i>Rhizoctonia solani</i>	Seedling damping-off	Various vegetables and ornamentals	Chen <i>et al.</i> 1996	laboratory
B5	43	Methyl-benzamides De-localisation of spectrin like proteins No resistance recorded				
C: RESPIRATION						
C1	39	Pyrimidineamines: Complex 1 NADH Oxido-reductase No resistance reported				

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
C2	7	SDHI fungicides (Succinate dehydrogenase inhibitors) Complex II succinate dehydrogenase				
		<i>Alternaria alternata</i>	Alternaria late blight	Pistachio	Avenot & Michallides 2007 Avenot <i>et al.</i> 2008	field resistance mechanism
		<i>Aspergillus nidulans</i>			White & Georgopoulos 1986	mutant study
		<i>Coprinus cinereus</i>			Ito <i>et al.</i> 2004	mutation study and genetic analysis
		<i>Botryotinia fuckeliana (Botrytis cinerea)</i>	Grey mould		Angelini <i>et al.</i> 2010	Laboratory genetic analysis
		<i>Botrytis cinerea</i>	Grey mould	Grapevine Strawberry Kiwi fruit Apple	FRAC 2007 FRAC 2007 Bardas <i>et al.</i> 2010 Yin <i>et al.</i> 2011	field field multiple resistance field
		<i>Botrytis elliptica</i>	Grey mould	Lilly	FRAC 2007	field
		<i>Corynespora cassiicola</i>	Corynespora leaf spot	Cucumber	Miyamoto <i>et al.</i> 2007 Ishii <i>et al.</i> 2007 Miyamoto <i>et al.</i> 2009 Miyamoto <i>et al.</i> 2010b	field (greenhouses) molecular mechanism full field report field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Didymella bryoniae</i>	Gummy stem blight	Cucurbits	FRAC 2007 Stevenson <i>et al.</i> 2008	field field
		<i>Mycosphaerella graminicola</i>	Leaf spot	Wheat	Skinner <i>et al.</i> 1998	laboratory mutation study
		<i>Podosphaera xanthii</i>	Powdery mildew	Melon Cucumber	FRAC 2007 Miyamoto <i>et al.</i> 2010a	field field (Japan, glasshouses)
		<i>Ustilago maydis</i>	Smut	Maize	Keon <i>et al.</i> 1991	laboratory mutation study
		<i>Ustilago nuda</i>	Loose smut	Barley	Leroux & Berthier 1988	field
C3	11	QoI fungicides (Quinone outside Inhib.) Complex III cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)				
		<i>Alternaria alternata</i>	Alternaria late blight	Pistachio	Ma <i>et al.</i> 2003 Avenot & Michallides 2007	field / laboratory field
		<i>Alternaria alternata</i>	Alternaria blotch	Apple	Ishii 2008	field
		<i>Alternaria alternata</i>	Alternaria brown spot	Citrus	Mondal <i>et al.</i> 2009	field
		<i>Alternaria alternata</i>	Leaf spot	Potato	FRAC 2011	field, G143A, Europe
		<i>Alternaria arborescens</i>	Alternaria late blight	Pistachio	Ma <i>et al.</i> 2003	field / laboratory
		<i>Alternaria mali</i>	Alternaria blotch	Apple	Lu <i>et al.</i> 2003	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Alternaria solani</i>	Leaf spot	Potato	Pasche <i>et al.</i> 2002, 2004, Pasche <i>et al.</i> 2005 Pasche & Gudmestad 2008	field resistance mechanism fitness of F129L
		<i>Alternaria tenuissima</i>	Alternaria late blight	Pistachio	Ma <i>et al.</i> 2003	field / laboratory
		<i>Ascochyta rabiei</i>	Ascochyta blight	Chickpea	Wise <i>et al.</i> 2009	field. Northern Great Plains / Pacific N West
		<i>Blumeria graminis</i> , see <i>Erysiphe graminis</i>				
		<i>Botrytis cinerea</i>	Grey mold	Strawberry Strawberry, citrus Kiwi fruit	Markoglou <i>et al.</i> 2006 FRAC 2007 Ishii 2008 Bardas <i>et al.</i> 2010	mutation study Field, G143A, Germany Field, Japan Multiple resistance
		<i>Cercospora beticola</i>	Leaf spot	Sugar beet	Keshav Burla <i>et al.</i> 2012 Bolton <i>et al.</i> 2013	Field G143A Italy Field G143A USA
		<i>Cercospora soja</i>	Frogeye spot	Soya	FRAC 2011	Field, G143A, USA
		<i>Colletotrichum graminicola</i>	Leaf spot	Annual bluegrass / bent grass	Avila-Adame <i>et al.</i> 2003	field
		<i>Colletotrichum gloeosporioides</i>	Anthraxnose	Strawberry	Ishii 2008	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Corynespora cassiicola</i>	Leaf spot, target spot	Cucumber	Ishii 2004 FRAC Brazil G143A 2012	field field
		<i>Didymella bryoniae</i>	Gummy stem blight	Cucurbits Watermelon	Olaya & Holm 2001 Langston 2002 Stevenson <i>et al.</i> 2002	field field field
		<i>Didymella rabiei</i>	Ascochyta blight	Chickpea	Gossen & Anderson 2004	field
		<i>Erysiphe graminis tritici</i>	Powdery mildew	Wheat	Heaney <i>et al.</i> 2000 Sierotzki <i>et al.</i> 2000a	field resistance mechanism
		<i>Erysiphe graminis hordei</i>	Powdery mildew	Barley	Heaney <i>et al.</i> 2000	field
		<i>Erysiphe necator</i> : see also <i>Uncinula necator</i>				
		<i>Fusicladium carpophilum</i>	Leaf spot	Almond	Foerster <i>et al.</i> 2009	California orchards
		<i>Glomerella cingulata</i> (<i>Colletotrichum gloeosporioides</i>)	Anthracnose	Strawberry	Ishii 2004	
		<i>Magnaporthe oryzae</i>	Leaf spot	<i>Lolium perenne</i> (perennial ryegrass)	Ma & Uddin 2009	Study on 1 field isolate
		<i>Microdochium nivale</i> <i>Microdochium majus</i>	Stem / head blight.	Wheat	Walker <i>et al.</i> 2009	isolates from seed
		<i>Microdochium nivale</i>	Head blight	Wheat	FRAC 2011	FRAC Japan report
		<i>Microdochium spp.</i>	Stem / head blight	CeStempeals	FRAC 2008	field, France, G143A confirmed

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Monilinia laxa</i> <i>M. fructigena</i> <i>M. fructicola</i>	Brown rots	Fruit	Meissner & Stammler 2010	Not resistance but evidence of an intron
		<i>Mycosphaerella fijiensis</i>	Black Sigatoka	Banana	Heaney <i>et al.</i> 2000 Sierotzki <i>et al.</i> 2000b Chin <i>et al.</i> 2001	field resistance mechanism field
		<i>Mycosphaerella graminicola</i> See also <i>Septoria tritici</i>	Leaf spot	Wheat	Armand <i>et al.</i> 2003 Clark 2005 Fraaije <i>et al.</i> 2005 Gisi <i>et al.</i> 2005	field field, review field field
		<i>Mycovellosiella natrassii</i>	Leaf mold	Eggplant / aubergine	Yano & Kawada 2003 Ishii 2004	field / laboratory field
		<i>Pestalotiopsis longiseta</i>	Gray blight	Tea	Omatsu <i>et al.</i> 2012	field
		<i>Phaeosphaeria nodorum</i>	Leaf blotch	Wheat	Blixt <i>et al.</i> 2009	field, molecular data
		<i>Pseudoperonospora cubensis</i>	Downy mildew	Cucumber	Heaney <i>et al.</i> 2000	field
		<i>Plasmopara viticola</i>	Downy mildew	Grapevine	Heaney <i>et al.</i> 2000 Gullino <i>et al.</i> 2004 Sierotzki <i>et al.</i> 2005	field field review
		<i>Podosphaera fusca</i>	Powdery mildew	Cucumber	Ishii <i>et al.</i> 2001 Fernandez-Ortuno <i>et al.</i> 2006 Fernandez-Ortuno <i>et al.</i> 2008	Field Resistance mechanism
		<i>Podosphaera xanthii</i>	Powdery mildew	Cucurbits	McGrath & Shishkoff 2003a, b	field trial

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Pseudoperonospora cubensis</i>	Downy mildew	Cucumber	Heaney <i>et al.</i> 2000 Ishii <i>et al.</i> 2001	field field
		<i>Pyrenophora teres</i>	Net blotch	Barley	FRAC Semar <i>et al.</i> 2007	field molecular analysis (F129L)
		<i>Pyrenophora tritici-repentis</i>	Tan spot	Wheat	Reimann & Deising 2005 FRAC	field field
		<i>Pyricularia grisea</i>	Gray leaf spot	Perennial ryegrass	Vincelli & Dixon 2002 Kim <i>et al.</i> 2003	field field / resistance mechanism
		<i>Pyricularia oryzae</i>	Blast	Rice	FRAC Japan	field (G143A)
		<i>Pythium aphanidermatum</i>	Damping off	Turf	Gisi <i>et al.</i> 2002 Olaya <i>et al.</i> 2003	laboratory field / resistance mechanism
		<i>Ramularia colli-cygni</i>	Necrotic leaf spot	Barley	FRAC 2006	field
		<i>Rhizoctonia solani</i>	Sheath spot	Rice	FRAC 2011	field, F129L, USA
		<i>Rhynchosporium secalis</i>	Scald, leaf blotch	Barley	FRAC 2008	field, single isolate, Picardie
		<i>Saccharomyces cerevisiae</i>			Di Rago <i>et al.</i> 1989	resistance mechanism
		<i>Septoria nodorum</i> , see <i>Sphaeosphaeria nodorum</i>				
		<i>Septoria tritici</i> See also <i>Mycosphaerella graminicola</i>	Leaf spot	Wheat	Fraaije & Lucas 2003	field

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Sphaerotheca aphans</i> var. <i>aphans</i>	Powdery mildew	Strawberry	Ishii 2008	field
		<i>Sphaerotheca fuliginea</i>	Powdery mildew	Cucumber	Heaney <i>et al.</i> 2000 Ishii <i>et al.</i> 2001	field field
		<i>Stemphylium vesicarium</i>	Brown spot	Pears	FRAC 2006 Alberoni <i>et al.</i> 2010a	field as above, field
		<i>Stemphylium vesicarium</i>	Purple spot / sand blast	Asparagus	FRAC 2006	field
		<i>Uncinula necator</i> (see also <i>Erysiphe necator</i>)	Powdery mildew	Grapevine	Wilcox <i>et al.</i> 2003	field
		<i>Ustilago maydis</i>	Smut	Maize	Ziogas <i>et al.</i> 2002	laboratory mutants
		<i>Venturia inaequalis</i>	Scab	Apple	Zheng <i>et al.</i> 2000 Farber <i>et al.</i> 2002 Steinfeld <i>et al.</i> 2002 Dux <i>et al.</i> 2005	laboratory mutants field trial field field
C4	21	QiI fungicides (Quinone inside Inhibitors) Complex III cytochrome bc1 (ubiquinone reductase) at Qi site				
		<i>Phytophthora capsici</i>	Stem / fruit rot	General	Kousik & Keinath 2008	Not specified
		<i>Saccharomyces cerevisiae</i>			Di Rago & Colson 1988	the basis of resistance
C5	29	Oxidative phosphorylation uncouplers				
		<i>Botrytis cinerea</i>	Grey mold	Adzuki bean	Tamura 2000	field (fluazinam)

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
C6	30	Organo tin compounds Inhibitors of oxidative phosphorylation, ATP synthase				
		<i>Cercospora beticola</i>	Leaf spot	Sugar beet	Giannopolitis 1978, Giannopolitis & Chrysayi- Tokousbalides M 1980	
C7	38	Thiophene carboxamides ATP production (proposed)				
		<i>Gaeumannomyces graminis</i>	Take-all	Wheat	Joseph-Horne <i>et al.</i> 2000 Russell <i>et al.</i> 2001 Freeman <i>et al.</i> 2005	field field / laboratory field
D AMINO ACIDS AND PROTEIN SYNTHESIS						
D1	9	AP fungicides (Anilinopyrimidines) Methionine biosynthesis (proposed) (cgs gene)				
		<i>Botrytis cinerea (Botryotinia fuckeliana)</i>	Grey mold	Grapevine	Forster & Staub 1996 Chapeland <i>et al.</i> 1999 Sergeeva <i>et al.</i> 2002 Baroffio <i>et al.</i> 2003	field experiments field field field experiments
		<i>Botrytis cinerea</i>	Grey mould	Lisianthus	Elad <i>et al.</i> 2008	field
		<i>Penicillium expansum</i>	Blue mould	Apple Apple (stored prod.)	Li & Xiao 2008 Xiao <i>et al.</i> 2011	Mutation study Samples from stores

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
D2	23	Enopyranuronic acid antibiotic. Protein synthesis				
		<i>Streptomyces lividans</i>			Nomura <i>et al.</i> 1991	laboratory
		<i>Pyricularia oryzae</i>	Rice blast	Rice	Sakurai & Naito 1976	laboratory cross resistance study
D3	24	Hexopyranosyl antibiotic. Protein synthesis				
		<i>Bacillus subtilis</i>		Not specified	Tominaga & Kobayashi 1978	Mutation
		<i>Pyricularia oryzae</i>	Rice blast	Finger millet	Taga <i>et al.</i> 1979	field isolates
		<i>Pyricularia oryzae</i>	Rice blast	Rice	Ito & Yamaguchi 1977 Sakurai <i>et al.</i> 1977 Sakurai & Naito 1976	field field laboratory cross resistance study
D4	25	Glucopyranosyl antibiotic (streptomycin). Protein synthesis				
		<i>Erwinia amylovora</i>	Fire blight	Pear Pear Various Pear, apple, quince	Moller <i>et al.</i> 1972 Schroth <i>et al.</i> 1979 Basim <i>et al.</i> 2001 Manulis <i>et al.</i> 2003	field surveys
		<i>Erwinia caratovora</i>	Bacterial stalk rot	Maize	Chakravarti & Anilkumar 1969.	<i>In-vitro</i>
		<i>Pseudomonas cichorii</i>		Lettuce	Matsuzaki <i>et al.</i> 1981	field
		<i>Pseudomonas lapsa</i>	Bacterial stalk rot	Maize	Chakravarti & Anilkumar 1969.	<i>In-vitro</i>
		<i>Pseudomonas syringae</i> pv. <i>syringae</i>	Blossom blast, canker	Pear	Spotts & Cervantes 1995	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Pseudomonas syringae</i> pv. tomato	Bacterial speck	Tomato	Silva & Lopes 1995	field
		<i>Pseudomonas viridiflava</i>		Lettuce	Matsuzaki <i>et al.</i> 1981	field
		<i>Xanthomonas campestris</i> pv. vesicatoria		Pepper and tomato	Minsavage <i>et al.</i> 1990	
D5	41	Tetracycline antibiotic. Protein synthesis				
		<i>Erwinia amylovora</i>	Fire blight	Apple, pear	Lacy <i>et al.</i> 1984 Basim <i>et al.</i> 2001	field strain selection field
		<i>Pseudomonas syringae</i> pv. tomato	Bacterial speck	Tomato	Silva & Lopes 1995	field
		<i>Pseudomonas syringae</i> pv. <i>syringae</i>	Blossom blast, canker	Pear	Spotts & Cervantes 1995	field
E: SIGNAL TRANSDUCTION						
E1	13	Aza-naphthalenes. Signal transduction, mechanism unknown				
		<i>Blumeria graminis</i> f.sp. <i>tritici</i> <i>Erysiphe necator</i>	Powdery mildew	Wheat Grapevine	Genet & Jaworska 2009	Baseline, cross resistance studies
		<i>Erysiphe graminis</i> f. sp. <i>hordei</i>	Powdery mildew	Barley	Hollomon <i>et al.</i> 1997	mutation
E2	12	PP fungicides (Phenylpyrroles). MAP / Histidine-kinase in osmotic signal transduction (os-2, HOG1)				
		<i>Alternaria brassicicola</i>	Leaf spot	Brassicas	Avenot <i>et al.</i> 2005	field / laboratory resistance mechanism

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Aspergillus parasiticus</i>		Artificial media	Markoglou <i>et al.</i> 2008	mutation study
		<i>Botryotinia fuckeliana</i>	Grey mold	Grapevine	Faretra & Pallastro 1993	mutation
		<i>Fusarium spp.</i>	Seed piece decay	Potato	Peters <i>et al.</i> 2008	Not specified
		<i>Penicillium digitatum</i>	Green mould	Not specified	Kanetis <i>et al.</i> 2008	Isolates from packing houses but no crop losses
		<i>Penicillium expansum</i>	Blue mould	Apple	Li & Xiao 2008	Mutation study
E3	2	Dicarboximides. MAP / Histidine-kinase in osmotic signal transduction (os-1, Daf1)				
		<i>Alternaria alternata</i>	Leaf spot	Passion fruit	Hutton D G	laboratory / field
		<i>Alternaria spp. alternata, tenuissima, arborescens</i> group	late blight	Pistachio	Ma & Michailides 2004	field / induced
		<i>Alternaria brassicicola</i>	Leaf spot	Brassicas	Avenot <i>et al.</i> 2005	field / laboratory resistance mechanism
		<i>Alternaria daucii</i>	Leaf spot / blight	Carrot	Strandberg 1984 Fancelli & Kimati 1991	laboratory
		<i>Botryosphaeria dothidea</i>	Panicle / shoot blight	Pistachio	Ma <i>et al.</i> 2001	laboratory / field
		<i>Botrytis cinerea</i>	Grey mold	Cucumber	Steekelenburg 1987	field
		<i>Botrytis cinerea</i>	Grey mold	Grapevine	Holz 1979 Leroux <i>et al.</i> 1982	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Botrytis cinerea</i>	Grey mold	Strawberry	Davis & Dennis 1979	field
		<i>Botrytis cinerea</i>	Grey mould	Lisianthus	Elad <i>et al.</i> 2008	field
		<i>Botrytis elliptica</i>	Grey mold	Bulbs	Hsiang & Chastener 1990	field
		<i>Botrytis squamosa</i>	Leaf blight	Onion	Tremblay <i>et al.</i> 2003	laboratory
		<i>Botrytis tulipae</i>	Tulip fire	Tulip	Chastagner & Riley 1987	field
		<i>Didymella bryoniae</i>	Grey mold	Cucumber	Steekelenburg 1987	field
		<i>Microdochium nivale</i>	Snow mold	Grass / golf course	Pennucci <i>et al.</i> 1990	field
		<i>Monilinia fructicola</i>	Brown rot / twig/ blossom blight	Stone fruit	Penrose <i>et al.</i> 1985 Elmer & Gaunt 1994	field
		<i>Monilinia laxa</i>	Brown rot	Apple	Katan & Shabi 1981	laboratory
		<i>Neurospora crassa</i>			Grindle 1984	laboratory mutation
		<i>Pyrenopeziza brassicae</i>	Light leaf spot	Oilseed rape / brassicas	Ilott & Ingram 1987	laboratory selection / mutation
		<i>Sclerotinia homeocarpa</i>	Dollar spot	<i>Agrostis palustris</i> (bent grass)	Detweiler <i>et al.</i> 1983	field
		<i>Sclerotinia minor</i>	Basal rot	Lettuce	Hubbard <i>et al.</i> 1997	field
		<i>Sclerotinia minor</i>	Sclerotinia blight	Peanut	Brenneman <i>et al.</i> 1987 Smith <i>et al.</i> 1995	laboratory field
		<i>Stemphylium vesicarium</i>	Brown spot	Pear	Alberoni <i>et al.</i> 2005 Alberoni <i>et al.</i> 2010b	field Resistance mechanism

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Ustilago maydis</i>	Smut	Maize	Orth <i>et al.</i> 1994	laboratory mutation
F LIPIDS AND MEMBRANE SYNTHESIS						
F1	Formerly dicarboximides	Reclassified into E3				
F2	6	Phospho-thiolates and dithiolanes. Phospholipid biosynthesis, methyltransferase				
		<i>Bipolaris oryzae</i>	Rice	Rice blast	Annamalai & Lalithakumari 1992	mutagenesis and field
		<i>Pyricularia oryzae</i>	Rice	Rice blast	Uesugi 1981	mutation and field
F3	14	AH fungicides (Aromatic Hydrocarbons, chlorophenyls, nitroanilines, and heteroaromatics). Lipid peroxidation (proposed)				
		<i>Botrytis cinerea</i>	Grey mold	Glasshouse vegetables	Esuruoso & Wood 1971 Hartill <i>et al.</i> 1983	laboratory / field cross resistance studies with dicarboximides, Group 2
		<i>Phytophthora drechsletii</i>	-	-	Zhu Zhi-feng <i>et al.</i> 2006	Laboratory UV mutation, etridiazole

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Rhizoctonia solani</i>	-	-	Anilkumar & Pandourange Gowda 1981 Van Bruggen & Arneson 1984	PCNB <i>in-vitro</i> adaptation Tolclofos-methyl, <i>in-vitro</i> adaptation
		<i>Sclerotium rolfsii</i>	Southern blight / stem rot	Peanut	Shim <i>et al.</i> 1998	field
F4	28	Carbamates. Cell membrane permeability, fatty acids (proposed)				
		<i>Pythium spp.</i> (propamocarb) <i>P. aphanidermatum</i> <i>P. cylindrosporium</i> <i>P. dissotocum</i> <i>P. heterothalicum</i> group F <i>P. irregulare</i> <i>P. splendens</i> <i>P. ultimum</i>	Damping off	Not specific but tested on geranium seedlings	Moorman et al. 2002, Moorman and Kim 2004	Glasshouse isolates
G: STEROL BIOSYNTHESIS IN MEMBRANES						
G1	3	DMI Fungicides (DeMethylation Inhibitors) SBI Class I. C14-demethylase in sterol biosynthesis (<i>erg11 / cyp 51</i>)				
IMPORTANT NOTE: The DMI group includes several areas of chemistry (See FRAC Code List) and many molecules. Individual molecules can differ widely in their activity spectrum. Cases are known where resistance to one molecule does not always lead to resistance to another molecule. Reasons for this phenomenon are not always clear but appear to be linked to differences in the intrinsic levels of activity between molecules. If in any doubt assume that cross resistance can happen.						
		<i>Aspergillus nidulans</i>	-	-	De Waard & van Nistelrooy 1979	genetic study
		<i>Blumeriella jaapii</i>	Leaf spot	Cherry	Proffer <i>et al.</i> 2006	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Botrytis cinerea</i>	Grey mold	Vegetables Various	Elad 1992 Stehmann & De Waard 1996	field laboratory investigation of lack of intrinsic activity
		<i>Cercospora beticola</i>	Leaf spot	Sugar beet	Henry & Trivellas 1989 Karaoglanidis <i>et al.</i> 2000	Laboratory mutants Field isolates
		<i>Cladosporium caryigenum</i>	Scab	Pecan	Reynolds <i>et al.</i> 1997	cross resistance, laboratory
		<i>Colletotrichum gloeosporioides</i>	Anthracnose	Mango	Gutierrez-Alonso <i>et al.</i> 2003	postharvest / laboratory
		<i>Erysiphe graminis f.sp. hordei</i>	Powdery mildew	Barley	Fletcher & Wolfe 1981	field
		<i>Erysiphe graminis f.sp. tritici</i>	Powdery mildew	Wheat	De Waard <i>et al.</i> 1986	field
		<i>Fusarium asiaticum</i> <i>Fusarium graminearum</i>	Fusarium head blight	Wheat	Yin <i>et al.</i> 2009	Lab study on isolates from China
		<i>Fusarium fujikuroi</i>	-	-	Zhao Zhi-hua <i>et al.</i> 2007	Laboratory mutation (prochloraz)
		<i>Fusarium solani. See Nectria haematococca var. cucurbitae</i>	Cucurbits	Foot rot	Kalamarakis <i>et al.</i> 1991	genetic study
		<i>Microdochium (Fusarium) nivale</i>	-	-	Cristani & Gambogi 1993	Laboratory
		<i>Monilinia fructicola</i>	Twig blight, brown rot	Stone fruit	Nuninger-Ney <i>et al.</i> 1989	Laboratory Field

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
					Elmer <i>et al.</i> 1992	
		<i>Mycosphaerella fijiensis</i>	Sigatoka	Banana	Anonymous 1992	
		<i>Mycosphaerella graminicola</i>	Leaf spot	Wheat	Metcalf <i>et al.</i> 2000 Mavroedi & Shaw 2005 HGCA 2005 Cools <i>et al.</i> 2005	field experiments field experiments field laboratory
		<i>Mycovellosiella natrassii</i>	Leaf mold	Eggplant	Yamaguchi <i>et al.</i> 2000	field
		<i>Nectria haematococca</i> var. <i>cucurbitae</i>	Cucurbits	Foot rot	Kalamarakis <i>et al.</i> 1991	laboratory genetics
		<i>Penicillium digitatum</i>	Citrus	Green mold	Eckert 1987	Laboratory selection
		<i>Penicillium italicum</i>	-	Blue mold	De Waard <i>et al.</i> 1982	laboratory
		<i>Pseudocercospora herpotrichoides</i> Lente or R type	Eyespot	Wheat	Leroux & Marchegay 1991	field
		<i>Puccinia horiana</i>	White rust	Chrysanthemum	Cevat 1992 Cook 2001	field field
		<i>Puccinia striiformis</i>	Yellow / stripe rust	Wheat	Bayles <i>et al.</i> 2000 Napier <i>et al.</i> 2000	sensitivity shift laboratory
		<i>Pyrenophora teres</i>	Net blotch	Barley	Sheridan <i>et al.</i> 1985	field
		<i>Pyrenophora tritici-repentis</i>	Tan spot	Wheat	Reimann & Deising 2005	field
		<i>Rhynchosporium secalis</i>	Leaf blotch, scald	Barley	Hunter <i>et al.</i> 1986 Kendall & Hollomon 1990 Kendall <i>et al.</i> 1993 Cooke <i>et al.</i> 2004	Glasshouse field Field isolates field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Sclerotinia homoeocarpa</i>	-	-	Vargas <i>et al.</i> 1992	laboratory
		<i>Septoria tritici</i>				See <i>Mycosphaerella graminicola</i>
		<i>Sphaerotheca fuliginea</i>	Powdery mildew	Cucumber	Schepers 1983, 1985a, 1985b	field
		<i>Sphaerotheca mors-uvae</i>	Powdery mildew	Blackcurrant	Goszczyński <i>et al.</i> 1988	field
		<i>Sphaerotheca pannosa</i>	Powdery mildew	Nectarine	Reuveni 2001	field
		<i>Trichoderma koningii</i>	-	-	Figueras-Roca <i>et al.</i> 1996	Laboratory
		<i>Uncinula necator</i>	Powdery mildew	Grapevine	Steva <i>et al.</i> 1990 Reidi & Steinkellner 1996 Miller & Gubler 2003	field field field
		<i>Ustilago avenae</i>	Loose smut	Oats	Hippe & Koller 1986	laboratory
		<i>Ustilago maydis</i>	Smut / blister smut	Maize	Walsh & Sisler 1981	laboratory
		<i>Venturia inaequalis</i>	Scab	Apple	Stanis & Jones 1985; Köller <i>et al.</i> 1991	field laboratory
		<i>Venturia nashicola</i>	Japanese pear scab	Pear	Tomita & Ishii 1998	field
G2	5	Amines (Morpholines) SBI Class II. Δ^{14} reductase and $\Delta^8 - \Delta^7$ isomerase in sterol biosynthesis (<i>erg24 / erg2</i>)				
		<i>Erysiphe graminis tritici</i>	Powdery mildew	Wheat	Napier <i>et al.</i> 2000	sensitivity shift

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Erysiphe graminis hordei</i>	Powdery mildew	Barley	Napier <i>et al.</i> 2000	sensitivity shift
		<i>Nectria haematococca</i>			Lasseron-De Felandre <i>et al.</i> 1999	laboratory mutants
		<i>Ustilago maydis</i>	Smut	Maize	Markoglou & Ziogas 1999, 2000, 2001	laboratory mutants
G3	17	Hydroxylanilides (SBI class III). 3-keto reductase C4-demethylation (<i>erg27</i>)				
		<i>Botrytis cinerea</i> (<i>Botryotinia fuckeliana</i>)	Grey mold	Grapevine	Baroffio <i>et al.</i> 2003 Ziogas <i>et al.</i> 2003 Saito <i>et al.</i> 2011	field experiments mutants field (New York)
		<i>Botrytis cinerea</i>	Grey mould	Lisianthus	Elad <i>et al.</i> 2008	field (low frequency)
G4	18	SBI Class IV. Squalene epoxidase in sterol biosynthesis (<i>erg1</i>) No resistance recorded				
H: GLUCAN SYNTHESIS						
H3	26	Glucopyranosyl antibiotic (validamycin). Trehalase and inositol biosynthesis				
		<i>Coprinus cinereus</i>			Shim <i>et al.</i> 1994	
H4	19	Polyoxins. Chitin synthase				
		<i>Cochliobolus heterostrophus</i>			Gafur <i>et al.</i> 1998	laboratory mutation
		<i>Alternaria alternata</i>	Black leaf spot	Pear	Gasonshi & Takanashi	

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Alternaria kikuchiana</i>	Alternaria leaf blotch	Apple, pear	Hori <i>et al.</i> 1976	laboratory study on resistance mechanism
		<i>Alternaria mali</i>	Black leaf spot	Apple	Hwang & Yun 1986	field isolates
		<i>Alternaria solani</i>		Not specified	Maria & Sullia 1986	laboratory adaptation study
		<i>Sclerotium rolfsii</i>		Not specified	Maria & Sullia 1986	laboratory adaptation study
H5	40	CAA fungicides (Carboxylic acid amides). Cellulose synthase				
		<i>Phytophthora capsici</i>	Stem and fruit rot	Peppers	Young <i>et al.</i> 2001 Young <i>et al.</i> 2005 Lu <i>et al.</i> 2010	laboratory selection cross resistance study field
		<i>Phytophthora infestans</i>	Late blight	Potato	Dereviagina <i>et al.</i> 1999 Stein & Kirk 2003 Yuan <i>et al.</i> 2006	unstable field isolates mutation mutation
		<i>Phytophthora melonis</i>	Foot rot	Cucumber/cucurbits	Lei Chen <i>et al.</i> 2012	mutation
		<i>Phytophthora parasitica</i>	Black shank	Tobacco	Chabane <i>et al.</i> 1993	mutation
		<i>Plasmopara viticola</i>	Downy mildew	Vines	Gisi <i>et al.</i> 2007 Blum <i>et al.</i> 2010	inheritance of resistance resistance mechanism
		<i>Pseudoperonospora cubensis</i>	Downy mildew	Cucurbits	Blum <i>et al.</i> 2011	resistance mechanism

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		I: MELANIN SYNTHESIS IN CELL WALL				
I1	16.1	MBI-R (Melanin biosynthesis Inhibitors: Reductase). Reductase in melanin biosynthesis				
		<i>Magnaporthe grisea</i> / <i>Pyricularia oryzae</i>	Rice blast	Rice	Zhang <i>et al.</i> 2006	UV light generated mutants
I2	16.2	MBI-D (Melanin biosynthesis Inhibitors: Dehydratase). Dehydratase in melanin biosynthesis				
		<i>Magnaporthe grisea</i> / <i>Pyricularia oryzae</i>	Rice blast	Rice	Yamaguchi <i>et al.</i> 2002 Sawada <i>et al.</i> 2004 Takagaki <i>et al.</i> 2004 Yamada <i>et al.</i> 2004	Field field resistance mechanism field
		P: HOST PLANT DEFENCE INDUCTION				
P1	P	Benzo-thiadiazole BTH. Salicylic acid pathway No resistance recorded				
P2	P	Benzisothiazole No resistance recorded				
P3	P	Thiadiazole-carboxamide No resistance recorded				
P4	P	Natural compound (Laminarin) No resistance recorded				

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
U: UNKNOWN MODE OF ACTION						
U	27	Cyanoacetamide oximes				
		<i>Plasmopara viticola</i>	Downy mildew	Grapevine	Gullino <i>et al.</i> 1997	field
U	33	Phosphonates				
		<i>Bremia lactucae</i>	Downy mildew	lettuce	Brown <i>et al.</i> 2004	field
		<i>Phytophthora citrophthora</i>	Collar rot / foot rots		Angeles Diaz Borrás & Vila Aguila 1988	<i>in vitro</i>
		<i>Plasmopara viticola</i>	Downy mildew	Grape vine	Khilare <i>et al.</i> 2003	field
		<i>Pythium aphanidermatum</i>		Not specified	Sanders <i>et al.</i> 1990	<i>in-vitro</i> mutation
U	34	Phthalamic acids No resistance recorded				
U	35	Benzotriazines No resistance recorded				
U	36	Benzene-sulfonamides No resistance recorded				
U	37	Pyradazinones No resistance recorded				
U	42	Thiocarbamate No resistance recorded				
U	U5	Thiazole carboxamides. Microtubule disruption (proposed) No resistance recorded				
U	U6	Phenyl-acetamide				
		<i>Sphaerotheca cucurbitae</i>	Powdery mildew	Cucumber	Hosokawa <i>et al.</i> 2006	glasshouses, Japan

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
U	U7	Cancelled: See E1				
Actin disruption (proposed)	U8	Benzophenone				
		<i>Blumeria graminis</i>	Powdery mildew	wheat	Top Agrar, Dec. 2009 Felsenstein <i>et al.</i> 2010 (as above)	field, Germany field, Germany
U	U10	Acrylonitrile No resistance recorded				
NC: NOT CLASSIFIED						
Not known	diverse	Various mineral oils, organic oils, potassium bicarbonate, material of biological origin.				
		<i>Botryotinia fuckeliana</i>	Resistant to <i>Bacillus subtilis</i> strain CL27		Li & Leifert 1994	Lab study
M: MULTISITE CONTACT ACTIVITY						
	M1	Inorganics, copper				
		<i>Pseudomonas</i> species: <i>P. cepacia</i> <i>P. gladioli</i> <i>P. syringae</i> pv. <i>actinidiae</i> <i>Agrobacterium</i> species: <i>A. radiobacter</i> <i>A. tumefaciens</i>		Not specified, laboratory isolates	Goto <i>et al.</i> 1994	<i>in-vitro</i> tests

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Xanthomonas axonopodis</i> pv. <i>citri</i>	Citrus canker	Grapefruit	Canteros 2002	Field
	M2	Inorganics, sulphur No resistance recorded				
	M3	Dithiocarbamates and relatives				
		<i>Botrytis cinerea</i>	Grey mold	Not specified	Barak & Edgington 1984	laboratory study
		<i>Helminthosporium halodes</i>	Leaf spot	Sugar cane	Reddy & Anilkumar 1989	laboratory study
	M4	Phthalimides				
		<i>Botrytis cinerea</i>	Grey mold	Not specified	Barak & Edgington 1984	laboratory study
		<i>Botrytis cinerea</i>		Grapevine	Fourie & Holz 2001	laboratory
		<i>Botrytis cinerea</i>	Grey mold	Glasshouse cucumber	Malathrakis 1989	glasshouse
	M5	Chloronitriles (phthalonitriles)				
		<i>Botrytis cinerea</i>	Grey mold	Not specified	Barak & Edgington 1984	laboratory study
		<i>Botrytis cinerea</i>	Grey mold	Glasshouse cucumber	Malathrakis 1989	
	M6	Sulphamides				
		<i>Botrytis cinerea</i>	Grey mold	Glasshouse cucumber	Malathrakis 1989	
	M7	Guanidines				
		<i>Venturia inaequalis</i>	Scab	Apple	Szkolnik & Gilpatrick 1969, 1971	Dodine
		<i>Hypomyces</i>	-	-	Kappas & Georgopoulos	Dodine, induced resistance

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		<i>Penicillium digitatum</i>	Green mold	Citrus	Wild 1983	
		<i>Penicillium italicum</i>	Blue mold	Lemon	Hartill <i>et al.</i> 1983	<i>in-vitro</i>
	M8	Triazines No resistance recorded				

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