FRAC
LIST OF PLANT PATHOGENIC ORGANISMS RESISTANT TO DISEASE CONTROL AGENTS

Revised January 2012

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.

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:

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 2012 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

Source: www.frac.info
January 2012

Mode of Action Code and Target Site	Group Name	FRAC Group Code
D: AMINO ACIDS AND PROTEIN SYNTHESIS		
D1: Methionine biosynthesis (proposed) (*cgs gene*)	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 (*os-2, HOG1*)	PP fungicides. Phenylpyrroles	12
E3: MAP/Histidine-kinase in osmotic signal transduction (*os-1, Daf1*)	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

Source: www.frac.info
January 2012

Mode of Action Code and Target Site	Group Name	FRAC Group Code
G: STEROL BIOSYNTHESIS IN MEMBRANES		
G1: C14 demethylase in sterol biosynthesis (*erg11/cyp51*)	DMI fungicides. DeMethylation Inhibitors. SBI Class 1	3
G2: Δ^{14} reductase and $\Delta^{8} - \Delta^{7}$isomerase in sterol-biosynthesis (*erg24, erg2*)	Amines ('morpholines'). SBI class II	5
G3: 3-keto reductase, C4-demethylation (*erg27*)	Hydroxyanilides. SBI class III	17
G4: Squalene epoxidase in sterol biosynthesis (*erg1*)	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 (proposed):	Natural compound	P

Source: www.frac.info
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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
Cancelled, see E1		U7
Actin disruption (proposed)	Benzophenone	U8
Cell membrane disruption (proposed)	Guanidines (dodine)	U12
Unknown	Quinoline	U13
Unknown	Pyrazolinone	U14
Unknown	thiazolidine	U15
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

Source: www.frac.info

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**				
		Bremia lactucae	Downy mildew	Lettuce	Crute *et al.* 1987; Crute & Harrison 1988	field, genetics
		Peronospora destructor	Downy mildew	Onion	Wright 2004	-
		Peronospora hyoscyami (syn. P tabacina)	Blue mold	Tobacco	Bruck *et al.* 1982	field
		Peronospora tabacina	Blue mold	Tobacco	Bruck *et al.* 1981	field
		Peronospora viciae	Downy mildew	Pea	Falloon *et al.* 2000	field
		Phytophthora cactorum	Crown rot / leather rot	Strawberry American ginseng	Bal *et al.* 1987 Hill & Hausbeck 2008	field field
		Phytophthora capsici	Stem rot	Lima bean pods	Davey *et al.* 2008	field
		Phytophthora cinnamomi	Root rot	Avocado	Darvas & Becker 1984	field
		Phytophthora citricola	Rot / die back		Joseph & Coffey 1984	*in-vitro* mutation
		Phytophthora citricola	Dieback	Azalea	Ferrin & Kabashima 1991	field / laboratory

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Phytophthora citrophthora	Collar rot / foot rots		Serrhini *et al.* 1985	*in-vitro*
		Phytophthora citrophthora	Collar rot / foot rots		Angeles Diaz Borras & Vila Aguila 1988	*in -vitro*
		Phytophthora erythroseptica	Pink rot	Potato	Lambert & Salas 1994 Taylor *et al.* 2002	field field
		Phytophthora infestans	Late blight	Potato	Davidse *et al.* 1981 Hartill *et al.* 1983 Davidse *et al.* 1983	field field field
		Phytophthora infestans	Late blight	Poroporo	Hartill *et al.* 1983	field
		Phytophthora megasperma f.sp. glycinea	Root rot	Soybean in-vitro	Lamboy & Paxton 1992	laboratory selection
		Phytophthora megasperma f.sp. medicaginis	Root rot	Lucerne	Davidse 1981	laboratory selection
		Phytophthora melonis	Foot rot	Cucurbits	Wu *et al.* 2011	field (China)
		Phytophthora nicotianae	Root rot	Ornamentals	Hu *et al.* 2008	field
		Phytophthora palmivora	Root rot	-	Lucas *et al.* 1990	laboratory induction
		Phytophthora parasitica	Downy mildew	Periwinkle	Ferrin & Kabashima 1991	field / laboratory
		Phytophthora parasitica var. nicotianae	Black shank	Tobacco	Shew 1985	laboratory
		Phytophthora porri	Downy mildew	Leek	Locke *et al.* 1997	field
		Phytophthora sojae (syn. P megasperma)	Stem / root rot	Soybean	Bhat *et al.* 1993	laboratory
		Phytophthora sp.	Root rot	African violet	Romano & Edgington 1985	field
		Plasmopara halstedii	Downy mildew	Sunflower	Albourie *et al.* 1998	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Plasmopara obducens	Downy mildew	Impatiens (Busy lizzy)	FRAC 2011 FRAG UK 2011	
		Plasmopara viticola	Downy mildew	Grapevine	Staub & Sozzi 1981 Bosshard & Schuepp 1983 Leroux & Clerjeau 1985	 field field
		Pseudoperonospora cubensis	Downy mildew	Cucumber	Reuveni *et al.* 1980	field
		Pythium aphanidermatum	Damping off	-	Sanders & Soika 1988	field
		Pythium aphanidermatum		Not specified / creeping bent grass	Sanders *et al.* 1990	*in-vitro* mutation / field
		Pythium aphanidermatum	Damping off	Ornamentals	Moorman *et al.* 2002	field
		Pythium cylindrosporum	Damping off	Ornamentals	Moorman *et al.* 2002	field
		Pythium dissotocum	Root rot	Carrot	White *et al.* 1988	field
		Pythium dissotocum	Root rot	Ornamentals	Moorman *et al.* 2002	field
		Pythium heterothallicum	Damping off	Ornamentals	Moorman *et al.* 2002	field
		Pythium irregulare	Damping off	Ornamentals	Moorman *et al.* 2002	field
		Pythium splendens	Damping off	Ornamentals	Moorman *et al.* 2002	field
		Pythium spp.	Cavity spot various	Carrot Potato	White *et al.* 1988 Porter *et al.* 2009	field / laboratory field
		Pythium ultimum	Watery wound rot	Potato	Taylor *et al.* 2002	field
		Pythium ultimum	Damping off	Ornamentals	Moorman *et al.* 2002	field
A2	**8**	**Hydroxy (2 amino) pyrimidines: Adenosine-deaminase**				
		Erysiphe graminis f.sp. *hordei*	Powdery mildew	Barley	Hollomon 1978	field
		Sphaerotheca fuliginea	Powdery mildew	Cucurbits	Schepers 1984 O'Brien *et al.* 1988	field

Source: www.frac.info

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
A3	**32**	**Heteroaromatics DNA / RNA synthesis (proposed)** No resistance recorded				
A4	**31**	**Carboxylic acids**				
		Erwinia amylovora	Fire blight	Pear	Manulis *et al.* 2003, Kleitman *et al.* 2005	field survey
		B MITOSIS AND CELL DIVISION				
B1	**1**	**MBC fungicides (Methyl Benzimidazole Carbamates)**				
		Alternaria alternata	Alternaria rot	Citrus	Sitton & Pierson 1982	field
		Ascochyta byj	Ascochyta blight	Vegetables	Steekelenburg 1973	laboratory
		Ascochyta pinodes	Leaf spot	Pea	Molinero *et al.* 1993	laboratory
		Ascochyta pisi	Leaf spot	Pea	Molinero *et al.* 1993	laboratory
		Aspergillus nidulans	Bearings rot	Banana	Hasti & Georgopoulos 1971	laboratory
		Botryodiplodia theobromae	Botryodiplodia rot	Fruits (Mango)	Spalding 1982	Laboratory
		Botrytis allii	Neck rot	Onion	Viljanen-Rollinson *et al.* 2007	Field (New Zealand)

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Botrytis cinerea	Grey mold	cyclamen	Bollen & Scholten 1971	laboratory
		Botrytis cinerea	Chocolate spot	Beans	Harrison J G 1984	field
		Botrytis cinerea	Grey rot	Grapes / Vines	Ehrenhardt *et al.* 1973 Leroux *et al.* 1982 Elad *et al.* 1988	field cross resistance to phenylcarbamates, Group 10
		Botrytis cinerea	Grey mould	Lisianthus	Elad *et al.* 2008	field
		Botrytis elliptica	Grey rot	Lily	Chastagner & Riley 1987 Hsiang & Chastagner 1990	field
		Botrytis squamosa	Leaf blight	Alliacea	Presly & Maude1982	laboratory
		Botrytis tulipae	Fire blight	Tulip	Chastagner & Riley 1987	field
		Ceratocystis ulmi	Dutch elm disease	Elm	Brasier & Gibbs 1975	laboratory
		Cercospora apii	Early blight	Celery	Berger 1973	field
		Cercospora arachidicola	Leafspot	Peanut	Clarke *et al.* 1974; Littrell 1974	field
		Cercospora beticola	Leafspot	Sugar beet	Georgopoulos & Dovas 1973	field
		Cercospora musae	Leafspot	Banana	See *Mycosphaerella musicola*	
		Cercosporidium personatum	Late Leafspot	Peanut	Clarke *et al.* 1974	field
		Cladobotryum dendroides	Cobweb disease	Mushrooms	McKay *et al.* 1998	laboratory
		Cladosporium carpophilum	Scab	Peach, Nectarine	Chandler *et al.* 1978	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Cladosporium cladosporioides	Fruit rot	Fruits	Dekker 1972	review
		Cladosporium cucumerinum	Cladosporium	Cucurbits	Dekker 1972	review
		Cladosporium fulvum	Flower rot	Fruits	Staunton 1975	field
		Coccomyces hiemalis	Cherry leaf spot	Cherry	Jones & Ehret 1981	field
		Colletotrichum cereale	Anthracnose	Turfgrass	Wong *et al.* 2008	field
		Colletotrichum coffeanum	Coffee berry disease	Coffee	Cook & Pereira	field
		Colletotrichum gloeosporioides	Anthracnose	Pome fruit	Spalding 1982	laboratory
		Colletotrichum lindemuthianum	Anthracnose	Bean	Meyer 1976	review
		Colletotrichum musae	Anthracnose	Banana	Griffee 1973	field
		Corynespora cassicola	target spot	tomato	Date *et al.* 2004	field
		Cryptocline cyclaminis	Anthracnose	Cyclamen	Garibaldi *et al.* 1987	field
		Cylindrocladium scoparium	Stem canker	Eucalyptus *Callistemon* sp., *Pistacia lentiscus*	Prest &Poppe 1988 Vitale *et al.*2009	field field
		Cylindrocladium scoparium	Stem canker	Eucalyptus	Prest &Poppe 1988	field
		Didymella bryoniae	Gummy stem blight	Cucurbits	Malathrakis & Vakalounakis 1983 Steekelenburg 1987	field
		Didymella lycopersici	Stem rot	Tomato		
		Drechslera oryzae	Brown spot	Rice	Annamali & Lalithakumari 1987	laboratory
		Elsinoë fawcetti	Scab	Citrus	Whiteside 1980a Ieki 1994	field
		Elsinoë veneta	Anthracnose	Raspberry	Munro *et al.* 1988	field
		Erysiphe cichoracaerum	Powdery mildew	Cucurbits	Abelentsev & Savchenko 1980	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Erysiphe graminis	Powdery mildew	Cereals	Vargas 1973	field
		Erysiphe polygoni	Powdery mildew	Cowpeas	Rodriguez & Melendez 1984	field
		Erythronium spp.	Yellow fawn	Lily	Duineveld & Beijersbergen 1975	field
		Fulvia fulva also see *Cladosporium fulvum*	Leaf mold	Tomato	Miao & Higgins 1986	laboratory
		Fusarium culmorum	Fusariose	Potato / Pink	Seppanen 1983 Hanson *et al.* 1996	field
		Fusarium graminearum	Fusarium head blight	Cereals	Chen *et al.* 2009	Laboratory / mutation study
		Fusarium nivale	Pink snow mold	Wheat	Tanaka *et al.* 1983	field
		Fusarium oxysporium f. sp. dianthi	Fusariose	Oeillet	Tramier & Bettachini 1974	field
		Fusarium oxysporium f. sp. gladioli	Fusariose	Gladiolus	Magie & Wilfret 1974	field
		Fusarium oxysporium f. sp. lycopersici	Fusariose	Tomato	Thanassoulopoulos *et al.* 1970	laboratory
		Fusarium oxysporium f. sp. tulipae	Fusariose	Tulip	Valaskova 1983	laboratory
		Fusarium oxysporium f. sp. Melonis	Fusariose	Melon	Bastels-Schooley & MacNeil 1971	laboratory
		Fusarium roseum	Fusariose	Rosa, turf	Smiley & Howard 1976	field
		Fusarium roseum var. *sambucinum*	Dry rot	Potato	Tivoli *et al.* 1986	field
		Fusarium solani f. sp. pisi	Fusariose	Solanaceae	Richardson 1973	field, laboratory

Source: www.frac.info

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Fusarium sulphureum	dry rot	Potato	Hanson *et al.* 1996	field
		Fusicladium effusum	Scab	Pecan	Littrell 1977	
		Gibberella fujikuroi	Fusariose	Rice	Ogawa 1988	field
		Gibberella zeae		Rice	Liu *et al.* 2010	lab analysis
		Gloeosporium spp.	Fruit rot	Apple		
		Glomerella acutata	Storage rot	Apple	Weber & Palm 2010	field isolates
		Guignardia citricarpa	Black spot	Citrus	Herbert & Grech 1985	field
		Helminthosporium solani	Silver scurf	Potato	Geary *et al.* 2007	field (USA)
		Hypomyces rosellus	Cobweb disease	Mushrooms	Fletcher & Yarham 1976	field
		Leveillula taurica	Powdery mildew	Tomato	Jones & Thompson 1982	field
		Monilinia cinerea	Brown rot	Rosa	Abelentsev & Golyshin 1973	laboratory
		Monilinia fructicola	Brown rot	Pome fruit	Jones & Ehret 1976	field
		Monilinia fructigena	Brown rot	Pome fruit	Abelentsev & Golyshin 1973	laboratory
		Monilinia laxa	Brown rot	Pome fruit	Ogawa *et al.* 1981	field
		Mycogone perniciosa	Wet bubble	Mushrooms	Fletcher & Yarham 1976	field
		Mycosphaerella brassicicola	Ring spot	Brassicas		
		Mycosphaerella citri	Greasy spot	Citrus	Whiteside 1980b	field
		Mycosphaerella fijiensis	Black spot	Banana	Stover 1979	field
		Mycosphaerella fragariae	Leaf spot	Strawberry	Remiro & Kimati 1974	field
		Mycosphaerella melonis	Leaf spot / gummy stem blight	Strawberry	Kato *et al.* 1984	field

Source: www.frac.info

		Mycosphaerella musicola	Yellow spot	Banana	Joya C 1982	field
		Neofabraea alba	Storage rot	Apple	Weber & Palm 2010	field isolates
		Neofabraea perennans	Storage rot	Apple	Weber & Palm 2010	field isolates
		Neonectria galligena	Storage rot	Apple	Weber & Palm 2010	field isolates

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Neurospora crassa	Red mold	Bread	Sisler 1971	laboratory
		Oidiopsis taurica	Powdery mildew	Artichoke		
		Oidium begoniae	Powdery mildew	Begonia		
		Penicillium brevicompactum			Bollen & Scholten 1971	laboratory
		Penicillium corymbiferum	Rot	Crocus	Bollen & Scholten 1971 Jarvis & Hargreaves 1973	laboratory field
		Penicillium digitatum	Green rot	Citrus / Pome fruit	Wild 1983	field
		Penicillium expansum	Blue mold	Pome fruit / pear	Wicks 1977	field
		Penicillium fructigenum		various	Iida W 1975	field
		Penicillium italicum	Blue rot	Citrus	Muirhead 1974; Yu 1981	field
		Penicillium oxalicum	Stem rot	Cucurbits		
		Penicillium sclerotigenum		Yellow yam	Plumbley *et al.* 1984	field
		Pezicula alba	Ripe spot	Pome fruits	Bielenin 1986	field
		Phoma clematidina	Wilt	Clematis	*	
		Phoma tracheiphila	Malsecco	Citrus	Gilmenez & Luisi. 1978	field
		Phomopsis citri	Stem-end rot	Citrus	Spalding 1982	laboratory
		Podosphaera leucotricha	Powdery mildew	Fruit trees	Suta & Radulescu 1986	laboratory
		Pseudocercosporella herpotrichoides	Eyespot	Cereals	Griffin *et al.* 1982	field
		Pyrenopeziza brassicae	Light leaf spot	Oilseed rape	Ilott *et al.* 1987	laboratory

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Rhyncosporium secalis	Leaf blotch/scald	Barley		
		Rhizoctonia solani	Brown Rhizoctonia	Solanaceae	Martin *et al.* 1984	laboratory
		Sclerotinia fructicola	Brown rot	Stone fruits	Whan J H 1976	field
		Sclerotinia homeocarpa	Dollar spot	Grass	Cole 1974 Detweiler *et al.* 1983 Wong S P 2003	field
		Sclerotinia sclerotorium	Sclerotiniose	Oilseed rape		
		Sclerotium spp.	Stem rot	Alliacea/Potato/Carrot		
		Septoria apiicola	Leaf spot	Celery		
		Septoria leucanthemi	Leaf spot	Chrysanthemum	Paulus *et al.* 1976	field
		Septoria tritici	Leaf spot	Cereals	Griffin & Fisher 1985	laboratory
		Sphaerotheca fuliginea	Powdery mildew	Cucurbits	Schroeder & Providenti 1971; Naegler *et al.* 1977	field
		Sphaerotheca humuli	Powdery mildew	Ornamental flowers	Iida 1975	field
		Sphaerotheca pannosa	Powdery mildew	Rosa / Peach tree	Jarvis & Slingsby 1975	field
		Sporobolomyces roseus	Pink yeast	Rosa (mutation)	Nachmias & Barash 1976	laboratory
		Stagonospora curtisii	Leaf scorch	Ornamental flowers / Narcisssus	Saniewska 1985	field
		Talaromyces flavis		Fruits	Katan *et al.* 1984	laboratory
		Tapesia yallundae	Eyespot	Cereals	see *P. herpotrichoides*	field

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Tapesia acuformis	Eyespot	Cereals	see *P. herpotrichoides*	field
		Trichoderma harzianum	Green mold	Soil / Mushrooms	Eastburn & Butler 1986	field
		Uncinula necator	Powdery mildew	Grapes / Vines	Naegler *et al.* 1977; Pearson 1980 Pearson & Taschenberg 1980	field
		Ustilago hordei	Barley covered smut	Barley	Ben-Yephet Y *et al.* 1975	laboratory
		Venturia inaequalis	Scab	Pome fruit	Kiebacher & Hoffmann 1976	field
		Venturia nashicola	Scab	Pome fruit	Ishii & Yamaguchi 1981	field
		Venturia pirina	Scab	Pome fruit	Shabi & Ben-Yephet 1976	field
		Verticillium albo-atrum	Verticillium	Pome fruits	Ververke 1983	laboratory
		Verticillium dahliae	Verticillium	Pome fruit / Solanacea	Locke & Thorpe 1976 McHugh & Schreiber 1984	field
		Verticillium fungicola	Verticillium	Mushrooms	Fletcher & Yarham 1976; Samuels & Johnston 1980	field
		Verticillium malthousei (= V fungicola)	Verticillium	Mushrooms	Lambert & Wuest 1973	field
		Verticillium tricorpus	Wilt	Tomato		

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
B2	**10**	**N-phenyl carbamates: β tubulin assembly in mitosis**				
		Botrytis cinerea	Grey mold	Grapevine	Elad *et al.* 1988 Katan *et al.* 1989 Elad *et al.* 1992	cross resistance to phenylcarbamates, Group 10 field field
		Corynespora cassicola	Target spot	Tomato	Date *et al.* 2004	field
		Neurospora crassa			Fujimura *et al.* 1994	resistance mechanism
		Verticillium fungicola	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)**				
		Rhizoctonia solani	Seedling damping-off	Various vegetables and ornamentals	Chen *et al.* 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				
C2	**7**	**SDHI fungicides (Succinate dehydrogenase inhibitors) Complex II succinate dehydrogenase**				
MOA Code	**FRAC Group Code**	**Pathogen**	**Common name**	**Crop**	**Reference**	**Remarks**
		Alternaria alternata	Alternaria late blight	Pistachio	Avenot & Michallides 2007 Avenot *et al.* 2008	field resistance mechanism
		Aspergillus nidulans			White & Georgopoulos 1986	mutant study
		Coprinus cinereus			Ito *et al.* 2004	mutation study and genetic analysis
		Botryotinia fuckeliana (Botrytis cinerea)	Grey mould		Angelini *et al.* 2010	Laboratory genetic analysis
		Botrytis cinerea	Grey mould	Grapevine Strawberry Kiwi fruit Apple	FRAC 2007 FRAC 2007 Bardas *et al.*2010 Yin *et al.* 2011	field field multiple resistance field
		Botrytis elliptica	Grey mould	Lilly	FRAC 2007	field
		Corynespora cassiicola	Corynespora leaf spot	Cucumber	Miyamoto *et al.* 2007 Ishii *et al.* 2007 Miyamoto *et al.* 2009 Miyamoto *et al.* 2010b	field (greenhouses) molecular mechanism full field report field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Didymella bryoniae	Gummy stem blight	Cucurbits	FRAC 2007 Stevenson *et al.* 2008	field field
		Mycosphaerella graminicola	Leaf spot	Wheat	Skinner *et al.* 1998	laboratory mutation study
		Podosphaera xanthii	Powdery mildew	Melon Cucumber	FRAC 2007 Miyamoto *et al.* 2010a	field field (Japan, glasshouses)
		Ustilago maydis	Smut	Maize	Keon *et al.* 1991	laboratory mutation study
		Ustilago nuda	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)**				
		Alternaria alternata	Alternaria late blight	Pistachio	Ma *et al.* 2003 Avenot & Michallides 2007	field / laboratory field
		Alternaria alternata	Alternaria blotch	Apple	Ishii 2008	field
		Alternaria alternata	Alternaria brown spot	Citrus	Mondal *et al.* 2009	field
		Alternaria alternata	Leaf spot	Potato	FRAC 2011	field, G143A, Europe
		Alternaria arborescens	Alternaria late blight	Pistachio	Ma *et al.* 2003	field / laboratory
		Alternaria mali	Alternaria blotch	Apple	Lu *et al.* 2003	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Alternaria solani	Leaf spot	Potato	Pasche *et al.*2002, 2004, Pasche *et al*. 2005 Pasche & Gudmestad 2008	field resistance mechanism fitness of F129L
		Alternaria tenuissima	Alternaria late blight	Pistachio	Ma *et al.* 2003	field / laboratory
		Ascochyta rabiei	Ascochyta blight	Chickpea	Wise *et al.* 2009	field. Northern Great Plains / Pacific N West
		Blumeria graminis, see *Erysiphe graminis*				
		Botrytis cinerea	Grey mold	 Strawberry Strawberry, citrus Kiwi fruit	Markoglou *et al.* 2006 FRAC 2007 Ishii 2008 Bardas *et al.* 2010	mutation study Field, G143A, Germany Field, Japan Multiple resistance
		Cercospora sojina	Frogeye spot	Soya	FRAC 2011	Field, G143A, USA
		Colletotrichum graminicola	Leaf spot	Annual bluegrass / bent grass	Avila-Adame *et al.* 2003	field
		Colletotrichum gloeosporioides	Anthracnose	Strawberry	Ishii 2008	field
		Corynespora cassiicola	Leaf spot, target spot	Cucumber	Ishii 2004	field
		Didymella bryoniae	Gummy stem blight	Cucurbits Watermelon	Olaya & Holm 2001 Langston 2002 Stevenson *et al.* 2002	field field field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Didymella rabiei	Ascochyta blight	Chickpea	Gossen & Anderson 2004	field
		Erysiphe graminis tritici	Powdery mildew	Wheat	Heaney *et al.* 2000 Sierotzki *et al.* 2000a	field resistance mechanism
		Erysiphe graminis hordei	Powdery mildew	Barley	Heaney *et al.* 2000	field
		Erysiphe necator: see also *Uncinula necator*				
		Fusicladium carpophilum	Leaf spot	Almond	Foerster *et al.* 2009	California orchards
		Glomerella cingulata (Colletotrichum gloeosporioides)	Anthracnose	Strawberry	Ishii 2004	
		Magnaporthe oryzae	Leaf spot	*Lolium perenne* (perennial ryegrass)	Ma & Uddin 2009	Study on 1 field isolate
		Microdochium nivale *Microdochium majus*	Stem / head blight.	Wheat	Walker *et al.* 2009	isolates from seed
		Microdochium nivale	Head blight	Wheat	FRAC 2011	FRAC Japan report
		Microdochium spp.	Stem / head blight	CeStempeals	FRAC 2008	field, France, G143A confirmed
		Monilinia laxa *M. fructigena* *M. fructicola*	Brown rots	Fruit	Meissner & Stammler 2010	Not resistance but evidence of an intron
		Mycosphaerella fijiensis	Black Sigatoka	Banana	Heaney *et al.* 2000 Sierotzki *et al.* 2000b Chin *et al.* 2001	field resistance mechanism field

		Mycosphaerella graminicola See also *Septoria tritici*	Leaf spot	Wheat	Armand *et al.* 2003 Clark 2005 Fraaije *et al.* 2005 Gisi *et al.* 2005	field field, review field field
		Mycovellosiella nattrassii	Leaf mold	Eggplant / aubergine	Yano & Kawada 2003 Ishii 2004	field / laboratory field
		Phaeosphaeria nodorum	Leaf blotch	Wheat	Blixt *et al.* 2009	field, molecular data

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Pseudoperonospora cubensis	Downy mildew	Cucumber	Heaney *et al.* 2000	field
		Plasmopara viticola	Downy mildew	Grapevine	Heaney *et al.* 2000 Gullino *et al.* 2004 Sierotzki *et al.* 2005	field field review
		Podosphaera fusca	Powdery mildew	Cucumber	Ishii *et al.* 2001 Fernandez-Ortuno *et al.* 2006 Fernandez-Ortuno *et al.* 2008	Field Resistance mechanism
		Podosphaera xanthii	Powdery mildew	Cucurbits	McGrath & Shishkoff 2003a, b	field trial
		Pseudoperonospora cubensis	Downy mildew	Cucumber	Heaney *et al.* 2000 Ishii *et al.* 2001	field field
		Pyrenophora teres	Net blotch	Barley	FRAC Semar *et al.* 2007	field molecular analysis (F129L)
		Pyrenophora tritici-repentis	Tan spot	Wheat	Reimann & Deising 2005 FRAC	field field
		Pyricularia grisea	Gray leaf spot	Perennial ryegrass	Vincelli & Dixon 2002 Kim *et al.* 2003	field field / resistance mechanism

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Pythium aphanidermatum	Damping off	Turf	Gisi *et al.* 2002 Olaya *et al.* 2003	laboratory field / resistance mechanism
		Ramularia colli-cygni	Necrotic leaf spot	Barley	FRAC 2006	field
		Rhizoctonia solani	Sheath spot	Rice	FRAC 2011	field, F129L, USA
		Rhynchosporium secalis	Scald, leaf blotch	Barley	FRAC 2008	field, single isolate, Picardie
		Saccharomyces cerevisiae			Di Rago *et al.* 1989	resistance mechanism
		Septoria nodorum, see *Sphaeosphaeria nodorum*				
		Septoria tritici See also *Mycosphaerella graminicola*	Leaf spot	Wheat	Fraaije & Lucas 2003	field
		Sphaerotheca aphanis var. aphanis	Powdery mildew	Strawberry	Ishii 2008	field
		Sphaerotheca fuligenea	Powdery mildew	Cucumber	Heaney *et al.* 2000 Ishii *et al. 2001*	field field
		Stemphylium vesicarium	Brown spot	Pears	FRAC 2006 Alberoni *et al.* 2010a	field as above, field
		Stemphylium vesicarium	Purple spot / sand blast	Asparagus	FRAC 2006	field
		Uncinula necator (see also *Erysiphe necator*)	Powdery mildew	Grapevine	Wilcox *et al.* 2003	field
		Ustilago maydis	Smut	Maize	Ziogas *et al.* 2002	laboratory mutants

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January 2012

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Venturia inaequalis	Scab	Apple	Zheng *et al.* 2000 Farber *et al.* 2002 Steinfeld *et al.* 2002 Dux *et al.* 2005	laboratory mutants field trial field field
C4	**21**	**QiI fungicides (Quinone inside Inhibitors) Complex III cytochrome bc1 (ubiqinone reductase) at Qi site**				
		Phytophthora capsici	Stem / fruit rot	General	Kousik & Keinath 2008	Not specified
		Saccharomyces cerevisiae			Di Rago & Colson 1988	the basis of resistance
C5	**29**	**Oxidative phosphorylation uncouplers**				
		Botrytis cinerea	Grey mold	Adzuki bean	Tamura 2000	field (fluazinam)
C6	**30**	**Organo tin compounds Inhibitors of oxidative phosphorylation, ATP synthase**				
		Cercospora beticola	Leaf spot	Sugar beet	Giannopolitis 1978, Giannopolitis & Chrysayi-Tokousbalides M 1980	
C7	**38**	**Thiophene carboxamides ATP production (proposed)**				

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Gaeumannomyces graminis	Take-all	Wheat	Joseph-Horne *et al.* 2000 Russell *et al.* 2001 Freeman *et al.* 2005	field field / laboratory field
		D AMINO ACIDS AND PROTEIN SYNTHESIS				
D1	**9**	**AP fungicides (Anilinopyrimidines) Methionine biosynthesis (proposed) (cgs gene)**				
		Botrytis cinerea (Botryotinia fuckeliana)	Grey mold	Grapevine	Forster & Staub 1996 Chapeland *et al.* 1999 Sergeeva *et al*. 2002 Baroffio *et al.* 2003	field experiments field field field experiments
		Botrytis cinerea	Grey mould	Lisianthus	Elad *et al.* 2008	field
		Penicillium expansum	Blue mould	Apple Apple (stored prod.)	Li & Xiao 2008 Xiao *et al.* 2011	Mutation study Samples from stores
D2	**23**	**Enopyranuronic acid antibiotic. Protein synthesis**				
		Streptomyces lividans			Nomura *et al.* 1991	laboratory
		Pyricularia oryzae	Rice blast	Rice	Sakurai & Naito 1976	laboratory cross resistance study
D3	**24**	**Hexopyranosyl antibiotic. Protein synthesis**				
		Bacillus subtilis		Not specified	Tominaga & Kobayashi 1978	Mutation

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Pyricularia oryzae	Rice blast	Finger millet	Taga *et al.* 1979	field isolates
		Pyricularia oryzae	Rice blast	Rice	Ito & Yamaguchi 1977 Sakurai *et al.* 1977 Sakurai & Naito 1976	field field laboratory cross resistance study
D4	**25**	**Glucopyranosyl antibiotic (streptomycin). Protein synthesis**				
		Erwinia amylovora	Fire blight	Pear Pear Various Pear, apple, quince	Moller *et al.* 1972 Schroth *et al.* 1979 Basim *et al.* 2001 Manulis *et al.* 2003	field surveys
		Erwinia caratovora	Bacterial stalk rot	Maize	Chakravarti & Anilkumar 1969.	*In-vitro*
		Pseudomonas cichorii		Lettuce	Matsuzaki *et al.* 1981	field
		Pseudomonas lapsa	Bacterial stalk rot	Maize	Chakravarti & Anilkumar 1969.	*In-vitro*
		Pseudomonas syringae pv. *syringae*	Blossom blast, canker	Pear	Spotts & Cervantes 1995	field
		Pseudomonas syringae pv. tomato	Bacterial speck	Tomato	Silva & Lopes 1995	field
		Pseudomonas viridiflava		Lettuce	Matsuzaki *et al.* 1981	field
		Xanthomonas campestris pv. *vesicatoria*		Pepper and tomato	Minsavage *et al.* 1990	

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
D5	**41**	**Tetracycline antibiotic. Protein synthesis**				
		Erwinia amylovora	Fire blight	Apple, pear	Lacy *et al.* 1984 Basim *et al.* 2001	field strain selection field
		Pseudomonas syringae pv. tomato	Bacterial speck	Tomato	Silva & Lopes 1995	field
		Pseudomonas syringae pv. *syringae*	Blossom blast, canker	Pear	Spotts & Cervantes 1995	field
		E: SIGNAL TRANSDUCTION				
E1	**13**	**Aza-naphthalenes. Signal transduction, mechanism unknown**				
		Blumeria graminis f.sp. tritici *Erysiphe necator*	Powdery mildew	Wheat Grapevine	Genet & Jaworska 2009	Baseline, cross resistance studies
		Erysiphe graminis f. sp. *hordei*	Powdery mildew	Barley	Hollomon *et al.* 1997	mutation
E2	**12**	**PP fungicides (Phenylpyrroles). MAP / Histidine-kinase in osmotic signal transduction (os-2, HOG1)**				
		Alternaria brassicicola	Leaf spot	Brassicas	Avenot *et al.* 2005	field / laboratory resistance mechanism
		Aspergillus parasiticus		Artificial media	Markoglou *et al.* 2008	mutation study

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

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

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		F LIPIDS AND MEMBRANE SYNTHESIS

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
F1	Formerly dicarbox-imides	Reclassified into E3				
F2	**6**	**Phosphoro-thiolates and dithiolanes. Phospholipid biosynthesis, methyltransferase**				
		Bipolaris oryzae	Rice	Rice blast	Annamalai & Lalithakumari 1992	mutagenisis and field
		Pyricularia oryzae	Rice	Rice blast	Uesugi 1981	mutation and field
F3	**14**	**AH fungicides (Aromatic Hydrocarbons, chlorophenyls, nitroanilines, and heteroaromatics). Lipid peroxidation (proposed)**				
		Botrytis cinerea	Grey mold	Glasshouse vegetables	Esuruoso & Wood 1971 Hartill *et al.* 1983	laboratory / field cross resistance studies with dicarboximides, Group 2
		Phytophthora drechsleti	-	-	Zhu Zhi-feng *et al.* 2006	Laboratory UV mutation, etridiazole
		Rhizoctonia solani	-	-	Anilkumar & Pandourange Gowda 1981 Van Bruggen & Arneson 1984	PCNB *in-vitro* adaptation Tolclofos-methyl, *in-vitro* adaptation

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Sclerotium rolfsii	Southern blight / stem rot	Peanut	Shim *et al.* 1998	field
F4	**28**	**Carbamates. Cell membrane permeability, fatty acids (proposed)**				
		Pythium spp. (propamocarb) *P. aphanidermatum* *P cylindrosporium* *P. dissotocum* *P heterothalicum group F* *P. irregulare* *P. splendens* *P. ultimum*	Damping off	Not specified but tested on geranium seedlings	Moorman *et al.* 2002, Moorman & Kim 2004	glasshouse isolates
		G: STEROL BIOSYNTHESIS IN MEMBRANES				
G1	**3**	**DMI Fungicides (DeMethylation Inhibitors) SBI Class I. C14-demethylase in sterol biosynthesis (*erg11 / cyp 51)***				
	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.					
		Aspergillus nidulans	-	-	De Waard & van Nistelrooy 1979	genetic study
		Blumeriella jaapii	Leaf spot	Cherry	Proffer *et al.* 2006	field
		Botrytis cinerea	Grey mold	Vegetables	Elad 1992	field

				Various	Stehmann & De Waard 1996	laboratory investigation of lack of intrinsic activity
		Cercospora beticola	Leaf spot	Sugar beet	Henry & Trivellas 1989 Karaoglanidis *et al.* 2000	Laboratory mutants Field isolates
		Cladosporium caryigenum	Scab	Pecan	Reynolds *et al.* 1997	cross resistance, laboratory
		Colletotrichum gloeosporioides	Anthracnose	Mango	Gutierrez-Alonso *et al.* 2003	postharvest / laboratory
		Erysiphe graminis f .sp. *hordei*	Powdery mildew	Barley	Fletcher & Wolfe 1981	field
		Erysiphe graminis f .sp. *tritici*	Powdery mildew	Wheat	De Waard *et al.* 1986	field

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Fusarium asiaticum *Fusarium graminearum*	Fusarium head blight	Wheat	Yin *et al.* 2009	Lab study on isolates from China
		Fusarium fujikuroi	-	-	Zhao Zhi-hua *et al.* 2007	Laboratory mutation (prochloraz)
		Fusarium solani. See Nectria haematococca var. *cucurbiae*	Cucurbits	Foot rot	Kalamarakis *et al.* 1991	genetic study
		Microdochium (Fusarium) nivale	-	-	Cristani & Gambogi 1993	Laboratory
		Monilinia fructicola	Twig blight, brown rot	Stone fruit	Nuninger-Ney *et al.* 1989 Elmer *et al.* 1992	Laboratory Field
		Mycosphaerella fijiensis	Sigatoka	Banana	Anonymous 1992	
		Mycosphaerella graminicola	Leaf spot	Wheat	Metcalfe *et al.* 2000 Mavroedi & Shaw 2005 HGCA 2005 Cools *et al.* 2005	field experiments field experiments field laboratory
		Mycovellosiella nattrassii	Leaf mold	Eggplant	Yamaguchi *et al.* 2000	field
		Nectria haematococca var. *cucurbiae*	Cucurbits	Foot rot	Kalamarakis *et al.* 1991	laboratory genetics
		Penicillium digitatum	Citrus	Green mold	Eckert 1987	Laboratory selection
		Penicillium italicum	-	Blue mold	De Waard *et al.* 1982	laboratory

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MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Pseudocercosporella herpotrichoides Lente or R type	Eyespot	Wheat	Leroux & Marchegay 1991	field
		Puccinia horiana	White rust	Chrysanthemum	Cevat 1992 Cook 2001	field field
		Puccinia striiformis	Yellow / stripe rust	Wheat	Bayles *et al.* 2000 Napier *et al.* 2000	sensitivity shift laboratory
		Pyrenophora teres	Net blotch	Barley	Sheridan *et al.* 1985	field
		Pyrenophora tritici-repentis	Tan spot	Wheat	Reimann & Deising 2005	field
		Rhynchosporium secalis	Leaf blotch, scald	Barley	Hunter *et al.* 1986 Kendall & Hollomon 1990 Kendall *et al.* 1993 Cooke *et al.* 2004	Glasshouse field Field isolates field
		Sclerotinia homoeocarpa	-	-	Vargas *et al.* 1992	laboratory
		Septoria tritici				See *Mycosphaerella graminicola*
		Sphaerotheca fuligenea	Powdery mildew	Cucumber	Schepers 1983, 1985a, 1985b	field
		Sphaerotheca mors-uvae	Powdery mildew	Blackcurrant	Goszczynski *et al.* 1988	field
		Sphaerotheca pannosa	Powdery mildew	Nectarine	Reuveni 2001	field
		Trichoderma koningii	-	-	Figueras-Roca *et al.* 1996	Laboratory

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		Uncinula necator	Powdery mildew	Grapevine	Steva *et al.* 1990 Reidi & Steinkellner 1996 Miller & Gubler 2003	field field field
		Ustilago avenae	Loose smut	Oats	Hippe & Koller 1986	laboratory
		Ustilago maydis	Smut / blister smut	Maize	Walsh & Sisler 1981	laboratory
		Venturia inaequalis	Scab	Apple	Stanis & Jones 1985; Köller *et al.* 1991	field laboratory
		Venturia nashicola	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 (*erg24 / erg2*)**				
		Erysiphe graminis tritici	Powdery mildew	Wheat	Napier *et al.* 2000	sensitivity shift
		Erysiphe graminis hordei	Powdery mildew	Barley	Napier *et al.* 2000	sensitivity shift
		Nectria haematococca			Lasseron-De Felandre *et al.* 1999	laboratory mutants
		Ustilago maydis	Smut	Maize	Markoglou & Ziogas 1999, 2000, 2001	laboratory mutants
G3	**17**	**Hydroxyanilides (SBI class III). 3-keto reductase C4-demethylation *(erg27)***				
		Botrytis cinerea (Botryotinia fuckeliana)	Grey mold	Grapevine	Baroffio *et al.* 2003 Ziogas *et al.* 2003	field experiments mutants

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					Saito *et al.* 2011	field (New York)
MOA Code	**FRAC Group Code**	**Pathogen**	**Common name**	**Crop**	**Reference**	**Remarks**
		Botrytis cinerea	Grey mould	Lisianthus	Elad *et al.* 2008	field (low frequency)
G4	**18**	**SBI Class IV. Squalene epoxidase in sterol biosynthesis (*erg1)*** No resistance recorded				
		H: GLUCAN SYNTHESIS				
H3	**26**	**Glucopyranosyl antibiotic (validamycin). Trehalase and inositol biosynthesis**				
		Coprinus cinereus			Shim *et al.* 1994	
H4	**19**	**Polyoxins. Chitin synthase**				
		Cochliobolus heterostrophus			Gafur *et al.* 1998	laboratory mutation
		Alternaria alternata	Black leaf spot	Pear	Gasonshi & Takanashi	
		Alternaria kikuchiana	Alternaria leaf blotch	Apple, pear	Hori *et al.* 1976	laboratory study on resistance mechanism
		Alternaria mali	Black leaf spot	Apple	Hwang & Yun 1986	field isolates
		Alternaria solani		Not specified	Maria & Sullia 1986	laboratory adaptation study
		Sclerotium rolfsii		Not specified	Maria & Sullia 1986	laboratory adaptation study

H5	**40**	**CAA fungicides (Carboxylic acid amides). Cellulose synthase**				
		Phytophthora capsici	Stem and fruit rot	Peppers	Young *et al.* 2001 Young *et al.* 2005 Lu *et al.* 2010	laboratory selection cross resistance study field
		Phytophthora infestans	Late blight	Potato	Dereviagina *et al.* 1999 Stein & Kirk 2003 Yuan *et al.* 2006	unstable field isolates mutation mutation
		Phytophthora parasitica	Black shank	Tobacco	Chabane *et al.* 1993	mutation
		Plasmopara viticola	Downy mildew	Vines	Gisi *et al.* 2007 Blum *et al.* 2010	inheritance of resistance resistance mechanism
		Pseudoperonospora cubensis	Downy mildew	Cucurbits	Blum *et al.* 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**				
		Magnaporthe grisea / Pyricularia oryzae	Rice blast	Rice	Zhang *et al.* 2006	UV light generated mutants
I2	**16.2**	**MBI-D (Melanin biosynthesis Inhibitors: Dehydratase). Dehydratase in melanin biosynthesis**				

		Magnaporthe grisea / Pyricularia oryzae	Rice blast	Rice	Yamaguchi *et al.*2002 Sawada *et al.* 2004 Takagaki *et al.* 2004 Yamada *et al.* 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				

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
P3	**P**	**Thiadiazole-carboxamide** No resistance recorded				
P4	**P**	**Natural compound (Laminarin)** No resistance recorded				
		U: UNKNOWN MODE OF ACTION				
unknown	**27**	**Cyanoacetamide oximes**				
		Plasmopara viticola	Downy mildew	Grapevine	Gullino *et al.* 1997	field
unknown	**33**	**Phosphonates**				
		Bremia lactucae	Downy mildew	lettuce	Brown *et al.* 2004	field
		Phytophthora citrophthora	Collar rot / foot rots		Angeles Diaz Borras & Vila Aguila 1988	*in -vitro*
		Plasmopara viticola	Downy mildew	Grape vine	Khilare *et al.* 2003	field
		Pythium aphanidermatum		Not specified	Sanders *et al.* 1990	*in-vitro* mutation
unknown	34	**Phthalamic acids** No resistance recorded				
unknown	35	**Benzotriazines** No resistance recorded				

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
unknown	36	**Benzene-sulfonamides** No resistance recorded				
unknown	37	**Pyradazinones** No resistance recorded				
unknown	42	**Thiocarbamate** No resistance recorded				
	U5	**Thiazole carboxamides. Microtubule disruption (proposed)** No resistance recorded				
unknown	U6	**Phenyl-acetamide**				
		Sphaerotheca cucurbitae	Powdery mildew	Cucumber	Hosokawa *et al.* 2006	glasshouses, Japan
unknown	**U7**	**Cancelled: See E1**				
Actin disrup-tion (propose d)	**U8**	**Benzophenone**				
		Blumeria graminis	Powdery mildew	wheat	Top Agrar, Dec. 2009 Felsenstein *et al.* 2010 (as above)	field, Germany field, Germany
unknown	**U10**	**Acrylonitrile** No resistance recorded				

Source: www.frac.info

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
		NC: NOT CLASSIFIED				
unknown	**diverse**	**Various mineral oils, organic oils, potassium bicarbonate, material of biological origin.**				
		Botryotinia fuckeliana	Resistant to *Bacillus subtilis* strain CL27		Li & Leifert 1994	Lab study
		MULTI-SITE CONTACT ACTIVITY				
Multi-site contact activity	**M1**	**Inorganics, copper**				
		Pseudomonas species*:* *P. cepacia* *P. gladioli* *P. syringae pv. actinidiae* *Agrobacterium* species*:* *A. radiobacter* *A. tumefaciens*		Not specified, laboratory isolates	Goto *et al.* 1994	*in-vitro* tests
		Xanthomonas axonopodis pv. *citri*	Citrus canker	Grapefruit	Canteros 2002	Field
Multi-site contact activity	**M2**	**Inorganics, sulphur** No resistance recorded				
	M3	**Dithiocarbamates and relatives**				
		Botrytis cinerea *Helminthosporium halodes*	Grey mold Leaf spot	Not specified Sugar cane	Barak & Edgington 1984 Reddy & Anilkumar 1989	laboratory study laboratory study
	M4	**Phthalimides**				

Source: www.frac.info
January 2012

MOA Code	FRAC Group Code	Pathogen	Common name	Crop	Reference	Remarks
Multi-site contact activity		*Botrytis cinerea*	Grey mold	Not specified	Barak & Edgington 1984	laboratory study
		Botrytis cinerea	Grey mold	Grapevine	Fourie & Holz 2001	laboratory
		Botrytis cinerea	Grey mold	Glasshouse cucumber	Malathrakis 1989	glasshouse
	M5	**Chloronitriles (phthalonitriles)**				
		Botrytis cinerea	Grey mold	Not specified	Barak & Edgington 1984	laboratory study
Multi-site contact activity		*Botrytis cinerea*	Grey mold	Glasshouse cucumber	Malathrakis 1989	
	M6	**Sulphamides**				
		Botrytis cinerea	Grey mold	Glasshouse cucumber	Malathrakis 1989	
	M7	**Guanidines**				
		Venturia inaequalis	Scab	Apple	Szkolnik & Gilpatrick 1969, 1971	Dodine
Multi-site contact activity		*Hypomyces*	-	-	Kappas & Georgopoulos	Dodine, induced resistance
		Penicillium digitatum	Green mold	Citrus	Wild 1983	
		Penicillium italicum	Blue mold	Lemon	Hartill *et al.* 1983	*in-vitro*
	M8	**Triazines** No resistance recorded				

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