FRAC Code List ©*2015: Fungicides sorted by mode of action (including FRAC Code numbering)

INTRODUCTION

The following table lists commercial fungicides according to their mode of action and resistance risk. The most important bactericides are also included.

The Table headings are defined as:

MOA Code
Different letters (A to I, with added numbers) are used to distinguish fungicide groups according to their biochemical mode of action (MOA) in the biosynthetic pathways of plant pathogens. The grouping was made according to processes in the metabolism starting from nucleic acids synthesis (A) to secondary metabolism, e.g. melanin synthesis (I) at the end of the list, followed by host plant defence inducers (P), recent molecules with an unknown mode of action and unknown resistance risk (U, transient status, mostly not longer than 8 years, until information about mode of action and mechanism of resistance becomes available), and multi-site inhibitors (M).

Target Site and Code
If available, the biochemical mode of action is given. In many cases the precise target site is not known. However, a grouping can be made due to cross resistance profiles within a group or in relation to other groups.

Group Name
The Group Names listed are based on chemical relatedness of structures which are accepted in literature (e.g. The Pesticide Manual). They are based on different sources (chemical structure, site of action, first important representative in group).

Chemical Group
Grouping is based on chemical considerations. Nomenclature is according to IUPAC and Chemical Abstract name.

Common name
BSI/ISO accepted (or proposed) common name for an individual active ingredient expected to appear on the product label as definition of the product.

Comments on Resistance
Details are given for the (molecular) mechanism of resistance and the resistance risk. If field resistance is known to one member of the Group, it is most likely but not exclusively valid that cross resistance to other group members will be present. There is increasing evidence that the degree of cross resistance can differ between group members and pathogen species or even within species. For the latest information on resistance and cross resistance status of a particular pathogen / fungicide combination, it is advised to contact local FRAC representatives, product manufacturer's representatives or crop protection advisors. The intrinsic risk for resistance evolution to a given fungicide group is estimated to be **low, medium or high** according to the principles described in FRAC Monographs 1, 2 and 3. Resistance management is driven by intrinsic risk of fungicide, pathogen risk and agronomic risk (see FRAC pathogen risk list).

Similar classification lists of fungicides have been published by T. Locke on behalf of FRAG – UK (Fungicide Resistance, August 2001), and by P. Leroux (Classification des fongicides agricoles et résistance, Phytoma, La Défense des Végétaux, No. 554, 43-51, November 2002).

FRAC Code
Numbers and letters are used to distinguish the fungicide groups according to their cross resistance behaviour. The numbers were assigned primarily according to the time of product introduction to the market. The letters refer to P = host plant defence inducers, M = multi-site inhibitors, and U = unknown mode of action and unknown resistance risk. Reclassification of compounds based on new research may result in codes to expire. This is most likely in the U – section when the mode of actions gets clarified. These codes are not re-used for new groups; a note is added to indicate reclassification into a new code.

Last update: February 2015
Next update decisions: December 2015

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
A: nucleic acids synthesis	**A1:** RNA polymerase **I**	**PA** – fungicides (**P**henyl**A**mides)	acylalanines	benalaxyl benalaxyl-M (=kiralaxyl) furalaxyl metalaxyl metalaxyl-M (=mefenoxam)	Resistance and cross resistance well known in various Oomycetes but mechanism unknown. **High risk.** **See FRAC Phenylamide Guidelines for resistance management**	**4**
			oxazolidinones	oxadixyl		
			butyrolactones	ofurace		
	A2: adenosin-deaminase	hydroxy-(2-amino-) pyrimidines	hydroxy-(2-amino-) pyrimidines	bupirimate dimethirimol ethirimol	Medium risk Resistance and cross resistance known in powdery mildews. Resistance management required.	**8**
	A3: DNA/RNA synthesis (proposed)	heteroaromatics	isoxazoles	hymexazole	Resistance not known.	**32**
			isothiazolones	octhilinone		
	A4: DNA topoisomerase type II (gyrase)	carboxylic acids	carboxylic acids	oxolinic acid	Bactericide. Resistance known. Risk in fungi unknown. Resistance management required.	**31**
B: mitosis and cell division	**B1:** ß-tubuline assembly in mitosis	**MBC** - fungicides (**M**ethyl **B**enzimidazole **C**arbamates)	benzimidazoles	benomyl carbendazim fuberidazole thiabendazole	Resistance common in many fungal species. Several target site mutations, mostly E198A/G/K, F200Y in β-tubulin gene. Positive cross resistance between the group members. Negative cross resistance to N-Phenylcarbamates. **High risk. See FRAC Benzimidazole Guidelines for resistance management.**	**1**
			thiophanates	thiophanate thiophanate-methyl		
	B2: ß-tubulin assembly in mitosis	N-phenyl carbamates	N-phenyl carbamates	diethofencarb	Resistance known. Target site mutation E198K. Negative cross resistance to benzimidazoles. High risk. Resistance management required.	**10**
	B3: ß-tubulin assembly in mitosis	benzamides	toluamides	zoxamide	Low to medium risk. Resistance management required.	**22**
		thiazole carboxamide	ethylamino-thiazole-carboxamide	ethaboxam		
	B4: cell division (proposed)	phenylureas	Phenylureas	pencycuron	Resistance not known	**20**
	B5: delocalisation of spectrin-like proteins	benzamides	pyridinylmethyl-benzamides	fluopicolide	Resistance not known	**43**

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
C. respiration	**C1:** complex I NADH Oxido-reductase	pyrimidinamines	Pyrimidinamines	diflumetorim	Resistance not known.	**39**
		pyrazole-MET1	pyrazole-5-carboxamides	tolfenpyrad		
	C2: complex II: succinate-dehydro-genase	SDHI (**S**uccinate **deh**ydrogenase **i**nhibitors)	phenyl-benzamides	benodanil flutolanil mepronil	Resistance known for several fungal species in field populations and lab mutants. Target site mutations in sdh gene, e.g. H/Y (or H/L) at 257, 267, 272 or P225L, dependent on fungal species. Resistance management required. **Medium to high risk.** **See FRAC SDHI Guidelines for resistance management.**	**7**
			phenyl-oxo-ethyl thiophene amide	isofetamid		
			pyridinyl-ethyl-benzamides	fluopyram		
			furan- carboxamides	fenfuram		
			oxathiin-carboxamides	carboxin oxycarboxin		
			thiazole-carboxamides	thifluzamide		
			pyrazole-4-carboxamides	benzovindiflupyr bixafen fluxapyroxad furametpyr isopyrazam penflufen penthiopyrad sedaxane		
			pyridine-carboxamides	boscalid		
	C3: complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site *(cyt b gene)*	**QoI**-fungicides (**Q**uinone **o**utside **I**nhibitors)	methoxy-acrylates	azoxystrobin coumoxystrobin enoxastrobin flufenoxystrobin picoxystrobin pyraoxystrobin	Resistance known in various fungal species. Target site mutations in cyt b gene (G143A, F129L) and additional mechanisms. Cross resistance shown between all members of the QoI group. **High risk.** **See FRAC QoI Guidelines for resistance management.**	**11**
			methoxy-acetamide	mandestrobin		
			methoxy-carbamates	pyraclostrobin pyrametostrobin triclopyricarb		
			Oximino-acetates	kresoxim-methyl trifloxystrobin		
			oximino-acetamides	dimoxystrobin fenaminstrobin metominostrobin orysastrobin		
			oxazolidine-diones	famoxadone		
			dihydro-dioxazines	fluoxastrobin		
			Imidazolinones	fenamidone		
			benzyl-carbamates	pyribencarb		
	C4: complex III: cytochrome bc1(ubiquinone reductase) at Qi site	**QiI** - fungicides (**Q**uinone **i**nside **I**nhibitors)	cyano-imidazole	cyazofamid	Resistance risk unknown but assumed to be medium to high (mutations at target site known in model organisms). Resistance management required.	**21**
			sulfamoyl-triazole	amisulbrom		
	C5: uncouplers of oxidative phos-phorylation		dinitrophenyl crotonates	binapacryl meptyldinocap dinocap	Resistance not known. Also acaricidal activity.	**29**
			2,6-dinitro-anilines	fluazinam	Low risk. However, resistance claimed in *Botrytis* in Japan.	
			(pyr.-hydrazones)	(ferimzone)	Reclassified to U 14 in 2012.	

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
C: respiration (continued)	**C6:** inhibitors of oxidative phos-phorylation, ATP synthase	organo tin compounds	tri-phenyl tin compounds	fentin acetate fentin chloride fentin hydroxide	Some resistance cases known. Low to medium risk.	**30**
	C7: ATP production (proposed)	thiophene-carboxamides	thiophene-carboxamides	silthiofam	Resistance reported. Risk low.	**38**
	C8: complex III: cytochrome bc1 (ubiquinone reductase) at Qo site, stigmatellin binding sub-site	QoSI fungicides (Quinone outside Inhibitor, stigmatellin binding type)	triazolo-pyrimidylamine	ametoctradin	Not cross resistant to QoI fungicides. Resistance risk assumed to be medium to high (single site inhibitor). Resistance management required.	**45**
D: amino acids and protein synthesis	**D1:** methionine biosynthesis (proposed) *(cgs gene)*	**AP -** fungicides (**A**nilino-**P**yrimidines)	anilino-pyrimidines	cyprodinil mepanipyrim pyrimethanil	Resistance known in *Botrytis* and *Venturia*, sporadically in *Oculimacula* . **Medium risk.** **See FRAC Anilinopyrimidine Guidelines for resistance management.**	**9**
	D2: protein synthesis	enopyranuronic acid antibiotic	enopyranuronic acid antibiotic	blasticidin-S	Low to medium risk. Resistance management required.	**23**
	D3: protein synthesis	hexopyranosyl antibiotic	hexopyranosyl antibiotic	kasugamycin	Resistance known in fungal and bacterial (*P. glumae*) pathogens. Medium risk. Resistance management required.	**24**
	D4: protein synthesis	glucopyranosyl antibiotic	glucopyranosyl antibiotic	streptomycin	Bactericide. Resistance known. High risk. Resistance management required.	**25**
	D5: protein synthesis	tetracycline antibiotic	tetracycline antibiotic	oxytetracycline	Bactericide. Resistance known. High risk. Resistance management required.	**41**
E: signal transduction	**E1:** signal transduction (mechanism unknown)	aza-naphthalenes	aryloxyquinoline	quinoxyfen	Resistance to quinoxyfen known. Medium risk. Resistance management required. Cross resistance found in *Erysiphe (Uncinula) necator* but not in *Blumeria graminis*.	**13**
			quinazolinone	proquinazid		
	E2: MAP/Histidine-Kinase in osmotic signal transduction *(os-2, HOG1)*	**PP**-fungicides (**P**henyl**P**yrroles)	phenylpyrroles	fenpiclonil fludioxonil	Resistance found sporadically, mechanism speculative. Low to medium risk. Resistance management required.	**12**

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
E: signal transduction (continued)	**E3:** MAP/Histidine-Kinase in osmotic signal transduction *(os-1, Daf1)*	dicarboximides	dicarboximides	chlozolinate dimethachlone iprodione procymidone vinclozolin	Resistance common in *Botrytis* and some other pathogens. Several mutations in OS-1, mostly I365S. Cross resistance common between the group members. **Medium to high risk. See FRAC Dicarboximide Guidelines for resistance management.**	**2**
F: lipid synthesis and membrane integrity	**F1:**	formerly dicarboximides				
	F2: phospholipid biosynthesis, methyltrans-ferase	phosphoro-thiolates	phosphoro-thiolates	edifenphos iprobenfos (IBP) pyrazophos	Resistance known in specific fungi. Low to medium risk. Resistance management required if used for risky pathogens.	**6**
		dithiolanes	Dithiolanes	isoprothiolane		
	F3: lipid peroxidation (proposed)	**AH**-fungicides (**A**romatic **H**ydrocarbons) (chlorophenyls, nitroanilines)	aromatic hydrocarbons	biphenyl chloroneb dicloran quintozene (PCNB) tecnazene (TCNB) tolclofos-methyl	Resistance known in some fungi. Low to medium risk. Cross resistance patterns complex due to different activity spectra.	**14**
		heteroaromatics	1,2,4-thiadiazoles	etridiazole		
	F4: cell membrane permeability, fatty acids (proposed)	carbamates	carbamates	iodocarb propamocarb prothiocarb	Low to medium risk. Resistance management required.	**28**
	F5:	**formerly CAA**-fungicides				
	F6: microbial disrupters of pathogen cell membranes	microbial (*Bacillus* sp.)	*Bacillus* sp. and the fungicidal lipopeptides produced	*Bacillus subtilis* syn. *B.amyloliquefaciens** strain QST 713 *Bacillus amyloliquefaciens* strain FZB24 *Bacillus amyloliquefaciens* strain MBI600 *Bacillus amyloliquefaciens* strain D747	*synonyms for *Bacillus amyloliquefaciens* are *Bacillus subtilis* and *B. subtilis* var. *amyloliquefaciens* (previous taxonomic classification) Resistance not known. Induction of host plant defence described as additional mode of action for strain FZB24	**44**
	F7: cell membrane disruption (proposed)	plant extract	terpene hydrocarbons and terpene alcohols	extract from *Melaleuca alternifolia* (tea tree)	Resistance not known	**46**

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
G: sterol biosynthesis in membranes	**G1:** C14- demethylase in sterol biosynthesis *(erg11/cyp51)*	**DMI**-fungicides (**De**-**M**ethylation **I**nhibitors) (SBI: Class I)	piperazines	triforine	There are big differences in the activity spectra of DMI fungicides. Resistance is known in various fungal species. Several resistance mechanisms are known incl. target site mutations in cyp51 (erg 11) gene, e.g. V136A, Y137F, A379G, I381V; cyp51 promotor; ABC transporters and others. Generally wise to accept that cross resistance is present between DMI fungicides active against the same fungus. DMI fungicides are Sterol Biosynthesis Inhibitors (SBIs), but show no cross resistance to other SBI classes. **Medium risk.** **See FRAC SBI Guidelines for resistance management.**	**3**
			pyridines	pyrifenox pyrisoxazole		
			pyrimidines	fenarimol nuarimol		
			imidazoles	imazalil oxpoconazole pefurazoate prochloraz triflumizole		
			triazoles	azaconazole bitertanol bromuconazole cyproconazole difenoconazole diniconazole epoxiconazole etaconazole fenbuconazole fluquinconazole flusilazole flutriafol hexaconazole imibenconazole ipconazole metconazole myclobutanil penconazole propiconazole simeconazole tebuconazole tetraconazole triadimefon triadimenol triticonazole		
			triazolinthiones	prothioconazole		
	G2: Δ^{14}-reductase and $\Delta^{8}\rightarrow\Delta^{7}$-isomerase in sterol biosynthesis *(erg24, erg2)*	amines ("morpholines") (SBI: Class II)	morpholines	aldimorph dodemorph fenpropimorph tridemorph	Decreased sensitivity for powdery mildews. Cross resistance within the group generally found but not to other SBI classes. **Low to medium risk.** **See FRAC SBI Guidelines for resistance management.**	**5**
			piperidines	fenpropidin piperalin		
			spiroketal-amines	spiroxamine		
	G3: 3-keto reduc-tase, C4- de-methylation *(erg27)*	(SBI: Class III)	hydroxyanilides	fenhexamid	Low to medium risk. Resistance management required.	**17**
			amino-pyrazolinone	fenpyrazamine		
	G4: squalene-epoxidase in sterol biosynthesis *(erg1)*	(SBI class IV)	thiocarbamates	pyributicarb	Resistance not known, fungicidal and herbicidal activity	**18**
			allylamines	naftifine terbinafine	Medical fungicides only	

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
H: cell wall biosynthesis	**H3:** trehalase and inositol-biosynthesis	glucopyranosyl antibiotic	glucopyranosyl antibiotic	validamycin	Resistance not known. Induction of host plant defence claimed as additional MoA.	**26**
	H4: chitin synthase	polyoxins	peptidyl pyrimidine nucleoside	polyoxin	Resistance known. Medium risk. Resistance management required	**19**
	H5: cellulose synthase	**CAA**-fungicides (**C**arboxylic **A**cid **A**mides)	cinnamic acid amides	dimethomorph flumorph pyrimorph	Resistance known in *Plasmopara viticola* but not in *Phytophthora infestans*. Cross resistance between all members of the CAA group. **Low to medium risk. See FRAC CAA Guidelines for resistance management**	**40**
			valinamide carbamates	benthiavalicarb iprovalicarb valifenalate		
			mandelic acid amides	mandipropamid		
I: melanin synthesis in cell wall	**I1:** reductase in melanin biosynthesis	**MBI-R** (**M**elanin **B**iosynthesis **I**nhibitors – **R**eductase)	isobenzo-furanone	fthalide	Resistance not known	**16.1**
			pyrrolo-quinolinone	pyroquilon		
			triazolobenzo-thiazole	tricyclazole		
	I2: dehydratase in melanin biosynthesis	**MBI-D** (**M**elanin **B**iosynthesis **I**nhibitors – **D**ehydratase)	cyclopropane-carboxamide	carpropamid	Resistance known. Medium risk. Resistance management required	**16.2**
			carboxamide	diclocymet		
			propionamide	fenoxanil		
	I3: polyketide synthase in melanin biosynthesis	**MBI-P** (**M**elanin **B**iosynthesis **I**nhibitors – **P**olyketide synthase)	trifluoroethyl-carbamate	tolprocarb	Resistance not known	**16.3**
P: host plant defence induction	**P1:** salicylic acid pathway	benzo-thiadiazole BTH	benzo-thiadiazole BTH	acibenzolar-S-methyl	Resistance not known	**P 1**
	P2	benzisothiazole	benzisothiazole	probenazole (also antibacterial and antifungal activity)	Resistance not known	**P 2**
	P3	thiadiazole-carboxamide	thiadiazole-carboxamide	tiadinil isotianil	Resistance not known	**P 3**
	P4	natural compound	polysaccharides	laminarin	Resistance not known	**P 4**
	P5	plant extract	complex mixture, ethanol extract	extract from *Reynoutria sachalinensis* (giant knotweed)	Resistance not known	**P 5**

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
Unknown mode of action (U numbers not appearing in the list derive from reclassified fungicides)	unknown	cyanoacetamide-oxime	cyanoacetamide-oxime	cymoxanil	Resistance claims described. Low to medium risk. Resistance management required.	**27**
	unknown	phosphonates	ethyl phosphonates	fosetyl-Al	Few resistance cases reported in few pathogens. Low risk	**33**
				phophorous acid and salts		
	unknown	phthalamic acids	phthalamic acids	teclofthalam (Bactericide)	Resistance not known	**34**
	unknown	benzotriazines	benzotriazines	triazoxide	Resistance not known	**35**
	unknown	benzene-sulfonamides	benzene-sulphonamides	flusulfamide	Resistance not known	**36**
	unknown	pyridazinones	pyridazinones	diclomezine	Resistance not known	**37**
	unknown	thiocarbamate	thiocarbamate	methasulfocarb	Resistance not known	**42**
	unknown	phenyl-acetamide	phenyl-acetamide	cyflufenamid	Resistance in *Sphaerotheca*. Resistance management required	**U 6**
	actin disruption (proposed)	aryl-phenyl-ketone	benzophenone	metrafenone	Less sensitive isolates detected in wheat powdery mildew. Medium risk. Resistance management required.	**U 8**
			benzoylpyridine	pyriofenone		
	cell membrane disruption (proposed)	guanidines	guanidines	dodine	Resistance known in *Venturia inaequalis.* Low to medium risk. Resistance management recommended.	**U 12**
	unknown	thiazolidine	cyano-methylene-thiazolidine	flutianil	Resistance not known	**U 13**
	unknown	pyrimidinone-hydrazones	pyrimidinone-hydrazones	ferimzone	Resistance not known Reclassified from C5 in 2012	**U 14**
	oxysterol binding protein (OSBP) inhibition (proposed)	piperidinyl-thiazole-isoxazolines	piperidinyl-thiazole-isoxazolines	oxathiapiprolin	Resistance risk assumed to be medium to high (single site inhibitor). Resistance management required.	**U 15**
	complex III: cytochrome bc1, unknown binding site (proposed)	4-quinolyl-acetate	4-quinolyl-acetate	tebufloquin	Not cross resistant to QoI. Resistance risk unknown but assumed to be medium. Resistance management required.	**U 16**
	unknown	tetrazoyloxime	tetrazoyloxime	picarbutrazox	Resistance not known. Not cross resistant to PA, QoI, CAA	**U 17**

MOA	TARGET SITE AND CODE	GROUP NAME	CHEMICAL GROUP	COMMON NAME	COMMENTS	FRAC CODE
not clas-si-fied	unknown	diverse	diverse	mineral oils, organic oils, potassium bicarbonate, material of biological origin	Resistance not known	**NC**
Multi-site contact activity	multi-site contact activity	inorganic	inorganic	copper (different salts)	Generally considered as a low risk group without any signs of resistance developing to the fungicides	**M 1**
		inorganic	inorganic	sulphur		**M 2**
		dithiocarbamates and relatives	dithio-carbamates and relatives	ferbam mancozeb maneb metiram propineb thiram zineb ziram		**M 3**
		phthalimides	phthalimides	captan captafol folpet		**M 4**
		chloronitriles (phthalonitriles)	chloronitriles (phthalonitriles)	chlorothalonil		**M 5**
		sulfamides	sulfamides	dichlofluanid tolylfluanid		**M 6**
		guanidines	guanidines	guazatine iminoctadine		**M 7**
		triazines	triazines	anilazine		**M 8**
		quinones (anthraquinones)	quinones (anthra-quinones)	dithianon		**M 9**
		quinoxalines	quinoxalines	chinomethionat / quinomethionate		**M 10**
		maleimide	maleimide	fluoroimide		**M 11**