FRAC Classification of Fungicides
Fungal control agents by cross resistance pattern and mode of action 2024 (www.frac.info)
FRAC
FUNGICIDE RESISTANCE ACTION COMMITTEE
A: Nucleic Acids Metabolism
A1: RNA polymerase I
4: PA-fungicides (PhenylAmides)
benalaxyl
furalaxyl
metalaxyl
benalaxyl-M
acylalanines
metalaxyl-M
ofurace
oxadixyl
butyrolactones
oxazolidinones
Group 4
A2: adenosine -deaminase
8: hydroxy (2-amino)-pyrimidines
bupirimate
dimethirimol
ethirimol
Group 8
A3: DNA / RNA synthesis (prop.)
32: heteroaromatics
hymexazole
isoxazoles
octhilinone
isothiazolones
Group 32
A4: DNA topoisomerase type II (gyrase)
31: carboxylic acids
oxolinic acid (bactericide)
Group 31
A5: inhibition of dihydroorotate dehydrogenase within de novo pyrimidine biosynthesis
52: DHODHI-fungicides
ipflufenoquin
phenyl-propanol
quinofumelin
dihydroisoquinoline
Group 52
B: Cytoskeleton and Motor Proteins
B1: tubulin polymerization
1: MBC fungicides
(= Methyl Benzimidazole Carbamates)
benzimidazoles
fuberidazole
benomyl
thiabendazole
carbendazim
thiophanate-methyl
thiophanate
thiophanates
Group 1
B2: tubulin polymerization*
10 N-phenyl carbamates
diethofencarb
*negative cross-resistance to B1
Group 10
B4: cell division (unknown site)
20 phenylureas
pencycuron
phenylurea
Group 20
B3: tubulin polymerization
22 benzamides and thiazole carboxamides
zoxamide
toluamide
ethaboxam
ethylamino-thiazole carboxamide
Group 22
B5: delocalisation of spectrin-like proteins
43 benzamides
fluopimomide
pyridinylmethyl benzamides
fluopicolide
Group 43
B6: actin/myosin/fimbrin function
47 cyanoacrylates
50 aryl-phenyl-ketones
phenamacril
aminocyanoacrylates
pyriofenone
benzoylpyridine
metrafenone
benzophenone
Group 47
Group 50
B7: tubulin dynamics modulator
53 pyridazine
pyridachlometyl
pyridazine
Group 53
C: Respiration
C1: complex I NADH Oxido-reductase
39 pyrimidinamines,pyrazole-MET1, quinazoline
diflumetorim
pyrimidinamine
tolfenpyrad
pyrazole-5-carboxamide
fenazaquin
quinazoline
Group 39
C4: complex III
cytochrome bc1(ubiquinone reductase) at Qi site
21 QiI fungicides (Quinone inside Inhibitors)
Group 21
cyano-imidazole
cyazofamid
sulfamoyl-triazole
amisulbrom
picolinamide
fenpicoxamid
florylpicoxamid
C8: inhibition of complex III
cytochrome bc1 (ubiquinone reductase) at Qi and Qo sites (stigmatellin binding mode)
45 QioSI-fungicide (Quinone inside and outside inhibitor, stigmatellin binding mode)
ametoctradin
triazolo-pyrimidylamine
Group 45
C2: complex II: succinate-dehydrogenase
7 SDHI (Succinate DeHydrogenase Inhibitors)
fluxapyroxad
furametpyr
pyrazole - 4 - carboxamides
bixafen
sedaxane
fluindapyr
penflufen
phenyl-oxo-ethyl thiophene amide
penthiopyrad
isopyrazam
inpyrfluxam
thiazole - carboxamides
isofetamid
pyridinyl – ethyl - benzamides
benzovindiflupyr
cyclobutrifluram
phenyl-cyclobutyl pyridineamide
benodanil
thifluzamide
fluopyram
pyrazine - carboxamides
isoflucypram
N-cyclopropyl-N-Benzyl-pyrazole-carboxamides
pyraziflumid
mepronil
phenyl-benzamides
pyridine - carboxamides
oxycarboxin
oxathiin - carboxamides
boscalid
carboxin
fenfuram
furan-carboxamides
pydiflumetofen
N-methoxy-(phenyl-ethyl)-pyrazole-carboxamides
flutolanil
Group 7
C5: uncouplers of oxidative Phosphorylation # 29
meptyl dinocap
dinitrophenyl crotonates
binapacryl
2,6-dinitro-aniline
fluazinam
Group 29
C6: inhibitors of oxidative phosphorylation ATP synthase
30 organo tins
fentin acetate
fentin chloride
fentin hydroxide
Group 30
C7: ATP transport (proposed)
38 thiophene- carboxamides
silthiofam
Group 38
C3: complex III cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)
11 QoI fungicides (Quinone outside Inhibitors)
methoxy-carbamates
coumoxystrobin
enoxastrobin
picoxystrobin
methoxy-acrylates
azoxystrobin
pyraoxystrobin
flufenoxystrobin
oximino-acetamides
orysastrobin
fenaminstrobin
metominostrobin
dimoxystrobin
pyrametostrobin
triclopyricarb
pyraclostrobin
kresoxim-methyl
trifloxystrobin
oximino-acetates
fluoxastrobin
dihydro-dioxazines
mandestrobin
methoxy-acetamides
famoxadone
oxazolidine-diones
fenamidone
imidazolinones
pyribencarb
benzyl-carbamates
Group 11
11A QoI fungicides (Quinone outside Inhibitors); Subgroup A
metyltetraprole
Group 11A
D: Amino Acid and Protein Synthesis
D1: methionine biosynthesis (cgs gene) (proposed)
9 Anilino-Pyrimidines (AP fungicides)
cyprodinil
pyrimethanil
mepanipyrim
Group 9
D2: protein synthesis (ribosome, termination step)
23 enopyranuronic acid
blasticidin-S
Group 23
D3: protein synthesis (ribosome, initiation step)
24 hexopyranosyl antibiotics
kasugamycin
Group 24
D4: protein synthesis (ribosome, initiation step)
25 glucopyranosyl antibiotics
streptomycin (bactericide)
Group 25
D5: protein synthesis (ribosome, elongation step)
41 tetracycline antibiotics
oxytetracycline (bactericide)
Group 41
D6: leucyl-tRNA synthetase (LeuRS)
54 benzoxaboroles
tavaborole
Group 54
E: Signal Transduction
E1: signal transduction (mechanism unknown)
#13 azanaphthalenes
aryloxyquinoline
quinoxyfen
quinazolinone
proquinazid
Group 13
E2: osmotic signal transduction
▹ MAP / histidine- kinase (os-2, HOG1)
12 phenylpyrroles (PP- fungicides)
fenpiclonil
fludioxonil
Group 12
E3: osmotic signal transduction
▹ MAP / histidine kinase (os-1, Daf1)
2 dicarboximides
chlozolinate
iprodione
vinclozolin
procymidone
dimethachlone
Group 2
F: Lipid Synthesis or Transport / Membrane Integrity or Function
F2: phospholipid biosynthesis ▹ methyltransferase
6 phosphorothiolates & dithiolanes
pyrazophos
phosphorothiolates
iprobenfos
edifenphos
dithiolanes
iso-prothiolane
Group 6
F3: cell peroxidation (prop.)
14 aromatic hydrocarbons & heteroaromatics
aromatic hydrocarbons
dicloran
tecnazene (TCNB)
quintozene (PCNB)
biphenyl
tolclofos-methyl
chloroneb
etridiazole
1,2,4-thiadiazole
Group 14
F4: cell membrane permeability, fatty acids (prop.)
28 carbamates
prothiocarb
propamocarb
iodocarb
Group 28
F9: lipid homeostasis and transfer/storage
49 OSBPI Oxysterol binding protein homologue inhibition
oxathiapiprolin
fluoxapiproline
Piperidinyl thiazole - isoxazoline
Group 49
F8: ergosterol binding
48 polyene
natamycin (pimaricin)
Group 48
F10: interaction with lipid fraction of cell membrane, with multiple effects on cell membrane integrity
51 protein fragment
Polypeptide ASFBIOF01-02
polypeptide
Group 51
I: Melanin Synthesis in Cell Wall
I1: reductase in melanin biosynthesis
16.1 Melanin Biosynthesis Inhibitors: Reductase (MBI-R)
isobenzo-furanone
fthalide
pyrrolo-quinolione
pyroquilon
triazolobenzo-thiazole
tricyclazole
Group 16.1
I2: dehydratase in melanin biosynthesis
16.2 Melanin Biosynthesis Inhibitors: Dehydratase (MBI-D)
carboxamide
diclocymet
cyclopropane carboxamide
carpropamid
propionamide
fenoxanil
Group 16.2
I3: polyketide synthase in melanin biosynthesis
16.3 Melanin Biosynthesis Inhibitors: Polyketide synthase (MBI-P)
tolprocarb
trifluoroethyl-carbamate
Group 16.3
G: Sterol Biosynthesis in Membranes
G1: C14-demethylase in sterol biosynthesis (erg11/cyp51)
3 DMI-fungicides (DeMethylation Inhibitors) (SBI : Class I)
triazoles
etaconazole
epoxiconazole
diniconazole
piperazines
triforine
azaconazole
ipconazole
imibenconazole
fenbuconazole
tebuconazole
hexaconazole
bitertanol
metconazole
simeconazole
fluquinconazole
tetraconazole
mefentrifluconazole
pyridines
pyrifenox
pyrisoxazole
bromuconazole
myclobutanil
flusilazole
triadimefon
cyproconazole
penconazole
pyrimidines
nuarimol
fenarimol
flutriafol
triadimenol
difenoconazole
propiconazole
triticonazole
imazalil
triflumizole
pefurazoate
oxpoconazole
prothioconazole
triazolinthione
prochloraz
imidazoles
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Group 3
G2: Δ14-reductase and Δ8→ Δ7-isomerase in sterol biosynthesis (erg2, erg 24)
5 Amines("Morpholines") (SBI : Class II)
fenpropidin
piperidines
piperalin
aldimorph
fenpropimorph
spiroketal-amines
tridemorph
n = 10 to 13
n = 12: ~70%
morpholines
dodemorph
spiroxamine
Group 5
G3: 3-keto reductase in C4-de-methylation (erg27)
17 (KRI fungicides KetoReductase Inhibitors) (SBI : Class III)
hydroxyanilides
fenhexamid
amino-pyrazolinones
fenpyrazamine
Group 17
G4: squalene epoxidase in sterol biosynthesis (erg1)
18 (SBI : Class IV)
terbinafine
naftifine
allylamines
pyributicarb (herbicide)
thiocarbamates
Group 18
H: Cell Wall Biosynthesis
H4: chitin synthase
19 Polyoxins
Peptidyl Pyrimidine nucleoside
Polyoxin
Group 19
H5: cellulose synthase
40 Carboxylic Acid Amides (CAA fungicides)
dimethomorph
cinnamic acid amides
flumorph
pyrimorph
benthiavalicarb
valinamide carbamates
mandipropamid
iprovalicarb
valifenalate
mandelic acid amides
Group 40
P: Host Plant Defence Induction
P01: salicylate related
#P01 benzothiodiazole BTH
acibenzolar-S-methyl
Group P01
P02: salicylate related
#P02 benzothiazole
probenazole
Group P02
P03: salicylate related
#P03 thiadiazole carboxamide
isotianil
tiadinil
Group P03
P04: polysaccharide elicitors
laminarin
#P04 natural compound
Group P04
P05: anthraquinone elicitors
Reynoutria sachalinensis (Giant Knotweed Extract)
#P05 plant extract
Group P05
P06: microbial elicitors
#P06 microbial
Bacillus mycoides (Isolate J)
Bacterial Bacillus spp.
Cell walls of Saccharomyces cerevisiae Strain LAS117
Fungal Saccharomyces spp.
Group P06
P07: phosphonates
#P07 phosphonates
ethyl-phosphonates
fosetyl-al
H3PO3
phosphorous acid
Phosphorous acid
Group P07
P08: salicylate related
#P08 isothiazole
dichlobentiazox
Group P08
M: Chemicals with Multi-Site Activity
Cu
copper preparations
Group M01
inorganic (electrophiles)
S
Sulphur
Group M02
inorganic (electrophiles)
chlorothalonil
Group M05
chloronitriles (unspecified mechanism)
anilazine
Group M08
triazines (unspecified mechanism)
dithianon
Group M09
anthraquinones (electrophiles)
amobam
mancozeb
methasulfocarb
Group M12
thiocarbamates (electrophiles)
febram
zinc thiazole
captan
dichlofluanid
chinomethionat
Group M10
quinoxalines (electrophiles)
propineb
tolylfluanid
Group M06
sulphamides (electrophiles)
metiram
maneb
captafol
fluoroimide
Group M11
maleimides (electrophiles)
thiram
zineb
ziram
Group M03
dithiocarbamates & relatives (electrophiles)
folpet
Group M04
phthalimides (electrophiles)
mixture of iminoctadine and other polyamines
guazatine
iminoctadine
Group M07
bis-guanidines (membrane disruptors, detergents)
Unknown Mode of Action
•Temporary status; information on mode of action and / or resistance risk is still uncertain
cymoxanil
Group 27
cyanoacetamide-oxime
tecloftalam
Group 34
phthalamic acid
triazoxide
Group 35
benzotriazines
flusulfamide
Group 36
benzene-sulfonamides
diclomezine
Group 37
pyridazinones
cyflufenamid
Group U6
phenyl acetamides
flutianil
Group U13
cyano-methylene thiazolidine
ferimzone
Group U14
pyrimidinone-hydrazones
tebufloquin
Group U16
4-quinolyl acetate
picarbutrazox
Group U17
tetrazolyloxime
validamycin
Group U18
glucopyranosyl antibiotic
dodine
Group U12
guanidines
BM: Biologicals with Multiple Modes of Action
BM 01 : plant extract
Polypeptide (lectin)
Phenols, Sesquiterpenes, Triterpenoids, Coumarins
Terpene Hydrocarbons, Terpene alcohols and Terpene phenols
Group BM01
BM 02 : microbial (strains of living microbes or extract, metabolites)
Fungal Trichoderma spp.
Fungal Clonostachys spp.
Fungal Coniothyrium spp.
Fungal Hanseniaspora spp.
Fungal Saccharomyces spp.
Fungal Talaromyces spp.
Bacterial Bacillus spp.
Bacterial Erwinia spp. (peptide)
Bacterial Pseudomonas spp.
Bacterial Gluconobacter spp.
Bacterial Streptomyces spp.
Group BM02
BM 03 : purified metabolites from plant or microbial sources or synthetic versions of these metabolites
cinnamaldehyde
Group BM03
Common names are described in FRAC code list
NC : Not Specified
Mineral oils, organic oils, inorganic salts, material of biological origin
Group NC
Mode of action of fungicides based on the FRAC fungicide list (FRAC Code List ©, published at www.frac.info/publications)
The groupings can change when new results become known. Colour coded boxes with same group code represent accepted mode of action groups or, in cases where resistance is known, cross resistance groups. In spite of this general classification, cases of incomplete or even lacking cross resistance are known within some groups with some pathogens.
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Legend:
C: Respiration
C8: inhibition of complex III
cytochrome bc1(ubiquinone reductase) at Qo site stigmatellin binding sub site)
45 QoSI-fungicide (stigmatellin binding)
ametoctradin
triazolo-pyrimidylamine
Group 45
Mode of Action Group
Target Site and Code
FRAC Group Name
Compound (ISO Common Name)
FRAC Group (#)
Chemical or biological group
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