FRAC Classification of Fungicides

FRAC FUNGICIDE RESISTANCE ACTION COMMITTEE

Fungal control agents by cross resistance pattern and mode of action 2024 (www.frac.info)

A: Nucleic Acids Metabolism

A1: RNA polymerase I
4: PA-fungicides (Phenyl Amides)

benalaxyl, metalaxyl, furalaxyl, benalaxyl-M, metalaxyl-M — acylalanines

ofurace, oxadixyl — butyrolactones, oxazolidinones

Group 4

A2: adenosine -deaminase
8: hydroxy (2-amino)-pyrimidines

bupirimate, dimethirimol, ethirimol

Nimrod

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: benomyl, fuberidazole, carbendazim

thiophanates: thiophanate-methyl, thiophanate, thiabendazole

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 Qih fungicides (Quinone Inside Inhibitors)

cyano-imidazole: cyazofamid

sulfamoyl-triazole: amisulbrom

picolinamide: fenpicoxamid, florylpicoxamid

Group 21

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)

Sercadis

fluxapyroxad, penflufen — pyrazole - 4 - carboxamides

furametpyr, phenyl-oxo-ethyl thiophene amide — thiazole - carboxamides

isofetamid, thifluzamide — pyridine - carboxamides

pyrazole - 4 - carboxamides: bixafen, fluindapyr, sedaxane, inpyrfluxam

penthiopyrad, isopyrazam, benzovindiflupyr, pyrazine - carboxamides

Reflect

cyclobutrifluram, phenyl-cyclobutyl pyridineamide, isoflucypram, N-cyclopropyl-N-Benzyl-pyrazole-carboxamides

fluopyram, pyraziflumid, oxycarboxin, oxathiin - carboxamides, carboxin

benodanil, flutolanil, mepronil, phenyl-benzamides

fenfuram, furan-carboxamides, pydiflumetofen, N-methoxy-(phenyl-ethyl)-pyrazole-carboxamides

boscalid

Signum +

Group 7

C5: uncouplers of oxidative Phosphorylation # 29

meptyl dinocap, dinitrophenyl crotonates — 2,6-dinitro-aniline

binapacryl, 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-acrylates: enoxastrobin, coumoxystrobin, picoxystrobin, pyraoxystrobin

Amistar

azoxystrobin, flufenoxystrobin

Signum +

Stroby

kresoxim-methyl, oximino-acetates — trifloxystrobin

fluoxastrobin, dihydro-dioxazines

Nativo +

methoxy-acetamides: famoxadone, oxazolidine-diones, mandestrobin

methoxy-carbamates: pyrametostrobin, triclopyricarb, pyraclostrobin

oximino-acetamides: fenaminstrobin, orysastrobin, metominostrobin, dimoxystrobin

imidazolinones: fenamidone

benzyl-carbamates: pyribencarb

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)

pyrimethanil, cyprodinil, mepanipyrim

Switch +

Frupica

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

Switch +

Group 12

E3: osmotic signal transduction ▹ MAP / histidine kinase (os-1, Daf1)
2 dicarboximides

iprodione, chlozolinate, procymidone, vinclozolin, dimethachlone

Paraat

Group 2

F: Lipid Synthesis or Transport / Membrane Integrity or Function

F2: phospholipid biosynthesis ▹ methyltransferase
6 phosphorothiolates & dithiolanes

phosphorothiolates: pyrazophos, iprobenfos, edifenphos

Revus

dithiolanes: iso-prothiolane

Group 6

F3: cell peroxidation (prop.)
14 aromatic hydrocarbons & heteroaromatics

aromatic hydrocarbons: tecnazene (TCNB), dicloran, quintozene (PCNB), biphenyl, tolclofos-methyl, chloroneb

1,2,4-thiadiazole: etridiazole

Group 14

F4: cell membrane permeability, fatty acids (prop.)
28 carbamates

prothiocarb, propamocarb, iodocarb

Group 28

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

F9: lipid homeostasis and transfer/storage
49 OSBPI Oxysterol binding protein homologue inhibition

oxathiapiprolin

fluoxapiproline

Piperidinyl thiazole - isoxazoline

Group 49

I: Melanin Synthesis in Cell Wall

I1: reductase in melanin biosynthesis
16.1 Melanin Biosynthesis Inhibitors: Reductase (MBI-R)

isobenzo-furanone: fthalide

pyrrolo-quinolinone: 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, azaconazole, bitertanol, bromuconazole, cyproconazole, difenoconazole, epoxiconazole, ipconazole, fenbuconazole, fluquinconazole, metconazole, tebuconazole, tetraconazole, myclobutanil, flusilazole, penconazole, flutriafol, triadimefon, triadimenol, propiconazole, triticonazole, diniconazole, imibenconazole, hexaconazole, simeconazole, mefentrifluconazole

piperazines: triforine

pyridines: pyrifenox, pyrisoxazole

pyrimidines: nuarimol, fenarimol

imidazoles: imazalil, triflumizole, pefurazoate, oxpoconazole, prochloraz

triazolinthione: prothioconazole

Topas

Global Resistance Management App
Get the FRAC / HRAC / IRAC Posters to Go!

Group 3

G2: Δ^{14}-reductase and $\Delta^{8}\rightarrow\Delta^{7}$-isomerase in sterol biosynthesis (*erg2, erg 24*)
5 Amines("Morpholines") (SBI : Class II)

piperidines: fenpropidin, piperalin

spiroketal-amines: spiroxamine

morpholines: aldimorph, fenpropimorph, tridemorph (n = 10 to 13; n = 12 - 10%), dodemorph

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)

cinnamic acid amides: dimethomorph, flumorph, pyrimorph

valinamide carbamates: benthiavalicarb, iprovalicarb, valifenalate

mandelic acid amides: mandipropamid

Group 40

P: Host Plant Defence Induction

P01: salicylate related
#P01 benzothiadiazole 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

#P04 natural compound

laminarin

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.

Romeo

Group P06

P07: phosphonates
#P07 phosphonates

fosetyl-al — ethyl-phosphonates

H_3PO_3 — phosphorous acid

Group P07

P08: salicylate related
#P08 isothiazole

dichlobentiazox

Group P08

M: Chemicals with Multi-Site Activity

M01: copper preparations
Cu

inorganic (electrophiles)

Group M01

M02: Sulphur
S

Microthiol

inorganic (electrophiles)

Group M02

M05: chlorothalonil
chloronitriles (unspecified mechanism)

Group M05

M08: anilazine
triazines (unspecified mechanism)

Group M08

M09: dithianon
anthraquinones (electrophiles)

Group M09

M12: thiocarbamates (electrophiles)
methasulfocarb

Group M12

M10: quinoxalines (electrophiles)
chinomethionat

Group M10

M06: sulphamides (electrophiles)
dichlofluanid, tolylfluanid

Group M06

M11: maleimides (electrophiles)
fluoroimide

Group M11

M03: dithiocarbamates & relatives (electrophiles)
amobam, mancozeb, febram, metiram, propineb, zineb, thiram, zinc thiazole, captan, captafol, folpet, maneb, ziram

Captan 80

Group M03

M04: phthalimides (electrophiles)
folpet

Group M04

M07: bis-guanidines (membrane disruptors, detergents)
mixture of iminoctadine and other polyamines — guazatine, iminoctadine

Group M07

Unknown Mode of Action

•Temporary status; information on mode of action and / or resistance risk is still uncertain

cymoxanil — Group 27 — cyanoacetamide-oxime

teclofталam — Group 34 — phthalamic acid

triazoxide — Group 35 — benzotriazines

flusulfamide — Group 36 — benzene-sulfonamides

diclomezine — Group 37 — pyridazinones

cyflufenamid — Group 06 — phenyl acetamides

Tukumi

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. — T34

Fungal *Clonostachys* spp.

Fungal *Coniothyrium* spp.

Fungal *Hanseniaspora* spp.

Fungal *Saccharomyces* spp.

Fungal *Talaromyces* spp.

Contans

Amylo X

Bacterial *Bacillus* spp.

Bacterial *Erwinia* spp. (peptide) — Serenade

Taegro

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.

Although details presented herein are accurate to our knowledge at the time of publication, neither FRAC nor its member companies make any representation or warranty with regard to the content of this presentation, in particular with regard to its correctness and completeness. Neither FRAC nor its member companies assume any liability for the content of this presentation or its use.

Legend:

C: Respiration
C8: inhibition of complex III
cytochrome bc1(ubiquinone reductase) at Qo site stigmatellin binding sub site)
45 QoSI-fungicide (stigmatellin binding)

- Mode of Action Group
- Target Site and Code
- FRAC Group Name
- Compound (ISO Common Name)
- FRAC Group (#)
- Chemical or biological group

ametoctradin — triazolo-pyrimidylamine — Group 45