FRAC Classification of Fungicides

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FRAC FUNGICIDE RESISTANCE ACTION COMMITTEE

CropLife INTERNATIONAL

A: Nucleic Acids Metabolism

A1: RNA polymerase I — GROUP 4
4 PA-fungicides (PhenylAmides)

acylalanines: benalaxyl, benalaxyl-M, furalaxyl, metalaxyl, metalaxyl-M

butyrolactones: ofurace

oxazolidinones: oxadixyl

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

bupirimate, dimethirimol, ethirimol

A3: DNA / RNA synthesis (prop.) — GROUP 32
32 heteroaromatics

isoxazoles: hymexazole

isothiazolones: octhilinone

imino-tosyl pyrimidinone: flumetylsulforim

A4: DNA topoisomerase type II (gyrase) — GROUP 31
31 carboxylic acids

oxolinic acid (bactericide)

A5: inhibition of dihydroorotate dehydrogenase within *de novo* pyrimidine biosynthesis — GROUP 52
52 DHODHI-fungicides

phenyl-propanol: ipflufenoquin

dihydroisoquinoline: quinofumelin

B: Cytoskeleton and Motor Proteins

B1: tubulin polymerization — GROUP 1
1 MBC fungicides (= Methyl Benzimidazole Carbamates)

benzimidazoles: benomyl, carbendazim, fuberidazole, thiabendazole

thiophanates: thiophanate, thiophanate-methyl

B2: tubulin polymerization* — GROUP 10
10 N-phenyl carbamates

*negative cross-resistance to B1

diethofencarb

B3: tubulin polymerization — GROUP 22
22 benzamides and thiazole carboxamides

ethylamino-thiazole carboxamide: ethaboxam

toluamide: zoxamide

B4: cell division (unknown site) — GROUP 20
20 phenylureas

phenylurea: pencycuron

B5: delocalization of spectrin-like proteins — GROUP 43
43 benzamides

pyridinylmethyl benzamides: fluopicolide, fluopimomide

B6: actin/myosin/fimbrin function — GROUP 47, 50
47 cyanoacrylates / # 50 aryl-phenyl-ketones

aminocyanoacrylates: phenamacril

benzophenone: metrafenone

benzoylpyridine: pyriofenone

B7: tubulin dynamics modulator — GROUP 53
53 pyridazine

pyridazine: pyridachlometyl

C: Respiration

C1: complex I NADH oxido-reductase — GROUP 39
39 pyrimidinamines, pyrazole-MET1, quinazoline

pyrazole-5-carboxamide: tolfenpyrad

pyrimidinamine: diflumetorim

quinazoline: fenazaquin

C2: complex II: succinate-dehydrogenase — GROUP 7
7 SDHI (Succinate DeHydrogenase Inhibitors)

oxathiin-carboxamides: carboxin, oxycarboxin

phenyl-benzamides: benodanil, flutolanil, mepronil

furan-carboxamides: fenfuram

N-cyclopropyl-N-benzyl-pyrazole-carboxamides: isoflucypram

N-methoxy-(pheny-ethyl)-pyrazole-carboxamides: pydiflumetofen

pyrazole-4-carboxamides: benzovindiflupyr, bixafen, fluindapyr, fluxapyroxad, furametpyr, inpyrfluxam, isopyrazam, penflufen, penthiopyrad, sedaxane

pyrazine-carboxamides: pyraziflumid

pyridine-carboxamides: boscalid

thiazole-carboxamides: thifluzamide

pyridinyl-ethyl-benzamides: fluopyram

phenyl-cyclobutyl-pyridineamide: cyclobutrifluram

phenyl-oxo-ethyl thiophene amide: isofetamid

C3: complex III cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene) — GROUP 11
11 QoI fungicides (Quinone outside Inhibitors)

methoxy-acrylates: azoxystrobin, bifemetstrobin, coumoxystrobin, enoxastrobin, flufenoxystrobin, picoxystrobin, pyraoxystrobin

methoxy-acetamides: mandestrobin

imidazolinones: fenamidone

methoxy-carbamates: pyraclostrobin, pyrametostrobin, triclopyricarb

oximino-acetates: kresoxim-methyl, trifloxystrobin

dihydro-dioxazines: fluoxastrobin

oximino-acetamides: dimoxystrobin, fenaminstrobin, metominostrobin, orysastrobin

benzyl-carbamates: pyribencarb

oxazolidine-diones: famoxadone

GROUP 11A
11A QoI fungicides (Quinone outside Inhibitors); Subgroup A

metyltetraprole

C4: complex III cytochrome bc1(ubiquinone reductase) at Qi site — GROUP 21
21 QiI fungicides (Quinone inside Inhibitors)

sulfamoyl-triazole: amisulbrom

cyano-imidazole: cyazofamid

picolinamides: fenpicoxamid, florylpicoxamid

C5: uncouplers of oxidative phosphorylation — GROUP 29
29

dinitrophenyl crotonates: binapacryl, meptyl dinocap

2,6-dinitro-aniline: fluazinam

C6: inhibitors of oxidative phosphorylation ATP synthase — GROUP 30
30 organo tins

fentin acetate, fentin chloride, fentin hydroxide

C7: ATP transport (proposed) — GROUP 38
38 thiophene- carboxamides

silthiofam

C8: inhibition of complex III cytochrome bc1 (ubiquinone reductase) at Qi and Qo sites (stigmatellin binding mode) — GROUP 45
45 QioSI-fungicide (Quinone inside and outside Inhibitor, Stigmatellin binding mode)

triazolo-pyrimidylamine: ametoctradin

Unknown Mode of Action

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

cyanoacetamide-oxime: cymoxanil — GROUP 27

phthalamic acid: tecloftalam — GROUP 34

benzotriazines: triazoxide — GROUP 35

benzene-sulphonamides: flusulfamide — GROUP 36

pyridazinones: diclomezine — GROUP 37

phenyl acetamides: cyflufenamid — GROUP U06

guanidines: dodine — GROUP U12

cyano-methylene thiazolidine: flutianil — GROUP U13

pyrimidinone-hydrazones: ferimzone — GROUP U14

4-quinolyl acetate: tebufloquin — GROUP U16

glucopyranosyl antibiotic: validamycin — GROUP U18

tetrazolyloximes: picarbutrazox — GROUP U17

nereistoxin analogues: cartap hydrochloride — GROUP U19

D: Amino Acid and Protein Synthesis

D1: methionine biosynthesis (cgs gene) (proposed) — GROUP 9
9 Anilino-Pyrimidines (AP fungicides)

cyprodinil, mepanipyrim, pyrimethanil

D2: protein synthesis (ribosome, termination step) — GROUP 23
23 enopyranuronic acid

blasticidin-S

D3: protein synthesis (ribosome, initiation step) — GROUP 24
24 hexopyranosyl antibiotics

kasugamycin

D4: protein synthesis (ribosome, initiation step) — GROUP 25
25 glucopyranosyl antibiotics

streptomycin (bactericide)

D5: protein synthesis (ribosome, elongation step) — GROUP 41
41 tetracycline antibiotics

oxytetracycline (bactericide)

D6: leucyl-tRNA synthetase (LeuRS) — GROUP 54
54 benzoxaboroles

tavaborole

E: Signal Transduction

E1: signal transduction (mechanism unknown) — GROUP 9
13 azanaphthalenes

quinazolinone: proquinazid

aryloxyquinoline: quinoxyfen

E2: osmotic signal Transduction MAP / histidine- kinase (os-2, HOG1) — GROUP 12
12 phenylpyrroles (PP- fungicides)

fenpiclonil, fludioxonil

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

chlozolinate, dimethachlone, iprodione, procymidone, vinclozolin

F: Lipid Synthesis or Transport / Membrane Integrity or Function

F2: phospholipid biosynthesis methyltransferase — GROUP 6
6 phosphorothiolates & dithiolanes

phosphorothiolates: edifenphos, iprobenfos, pyrazophos

dithiolanes: iso-prothiolane

F8: ergosterol binding — GROUP 48
48 polyene

natamycin (pimaricin)

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

iodocarb, propamocarb, prothiocarb

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

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

1,2,4-thiadiazole: etridiazole

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

piperidinyl thiazole - isoxazoline: fluoxapiprolin, oxathiapiprolin

F10: interaction with lipid fraction of cell membrane, with multiple effects on cell membrane integrity — GROUP 51
51 protein fragment

polypeptide: Polypeptide ASFBIOF01-02

G: Sterol Biosynthesis in Membranes

G1: C14-demethylase in sterol biosynthesis (*erg11/cyp51*) — GROUP 3
3 DMI-fungicides (DeMethylation Inhibitors) (SBI : Class I)

triazoles: azaconazole, bitertanol, bromuconazole, cyproconazole, difenoconazole, diniconazole, epoxiconazole, etaconazole, fenbuconazole, fluquinconazole, imibenconazole, ipconazole, mefentriflu-conazole, metconazole, myclobutanil, penconazole, propiconazole, simeconazole, tebuconazole, tetraconazole, flusilazole, flutriafol, hexaconazole, triadimefon, triadimenol, triticonazole

imidazoles: imazalil, oxpoconazole, pefurazoate, prochloraz, triflumizole

pyridines: pyrifenox, pyrisoxazole

pyrimidines: fenarimol, nuarimol

piperazines: triforine

triazolinthione: prothioconazole

G2: Δ14-reductase and Δ8→Δ7-isomerase in sterol biosynthesis (*erg2, erg 24*) — GROUP 5
5 amines ("Morpholines") (SBI : Class II)

morpholines: aldimorph, dodemorph, fenpropimorph, tridemorph (n = 10 to 13; n = 12: ~70%)

piperidines: fenpropidin, dodemorph

spiroketal-amines: spiroxamine

G3:3-keto reductase in C4-de-methylation (*erg27*) — GROUP 17
17 (KRI fungicides KetoReductase Inhibitors) (SBI : Class III)

amino-pyrazolinones: fenhexamid, fenpyrazamine

G4: squalene epoxidase in sterol biosynthesis (*erg1*) — GROUP 18
18 (SBI : Class IV)

allylamines: naftifine, terbinafine

thiocarbamates: pyributicarb (herbicide)

P: Host Plant Defense Induction

GROUP P01
P01: salicylate related
P01 benzothiodiazole BTH

acibenzolar-S-methyl

GROUP P02
P02: salicylate related
P02 benzothiazole

probenazole

GROUP P03
P03: salicylate related
P03 thiadiazole carboxamide

isotianil, tiadinil

GROUP P04
P04: polysaccharide elicitors
P04 natural compound

laminarin

GROUP P05
P05: anthraquinone elicitors
P05 plant extract

Reynoutria sachalinensis (Giant Knotweed Extract)

GROUP P06
P06: microbial elicitors
P06 microbial

Bacterial *Bacillus* spp.: *Bacillus mycoides* (Isolate J)

Fungal *Saccharomyces* spp.: Cell walls of *Saccharomyces cerevisiae* Strain LAS117

GROUP P07
P07: phosphates
P07 phosphates

ethyl-phosphonates: fosetyl-al

phosphorous acid: H_3PO_3 phosphorous acid

GROUP P08
P08: salicylate related
P08 isothiazole

dichlobentiazox

GROUP P09
P09: peptide elicitors
P09 flagellin peptide

peptide derived from *Bacillus thuringiensis*: $C_{953}H_{162}N_{32}O_{34}$ Flg22-Bt peptide

GROUP P10
P10: defense priming agents
P10 natural small molecule metabolite

ascaroside: ascr#18

H: Cell Wall Biosynthesis

H4: chitin synthase — GROUP 19
19 polyoxins

peptidyl pyrimidine nucleoside: polyoxin

H5: cellulose synthase — GROUP 40
40 Carboxylic Acid Amides (CAA fungicides)

cinnamic acid amides: dimethomorph, flumorph, pyrimorph

mandelic acid amides: mandipropamid

valinamide carbamates: benthiavalicarb, iprovalicarb, valifenalate

I: Melanin Synthesis in Cell Wall

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

isobenzo-furanone: fthalide

pyrrolo-quinolione: pyroquilon

triazolobenzo-thiazole: tricyclazole

I2: dehydratase in melanin biosynthesis — GROUP 16.2
16.2 MBI-D (Melanin Biosynthesis Inhibitors: Dehydratase)

carboxamide: diclocymet

cyclopropane carboxamide: carpropamid

propionamide: fenoxanil

I3: polyketide synthase inmelanin biosynthesis — GROUP 16.3
16.3 MBI-P (Melanin Biosynthesis Inhibitors: Polyketide synthase)

trifluoroethyl-carbamate: tolprocarb

BM: Biologicals with Multiple Modes of Action

GROUP BM01
BM 01: plant extract

phenols, sesquiterpenes, triterpenoids, coumarins

polypeptide (lectin)

terpene hydrocarbons, terpene alcohols, and terpene phenols

GROUP BM02
BM 02: microbial
(strains of living microbes or extract, metabolites)

Fungal *Clonostachys* spp.	Fungal *Coniothyrium* spp.	Bacterial *Bacillus* spp.	Bacterial *Erwinia* spp. (peptide)
Fungal *Hanseniaspora* spp.	Fungal *Talaromyces* spp.	Bacterial *Gluconobacter* spp.	Bacterial *Pseudomonas* spp.
Fungal *Trichoderma* spp.	Fungal *Saccharomyces* spp.	Bacterial *Streptomyces* spp.	Protozoal *Willaertia spp.*

GROUP BM03
cinnamaldehyde

BM 03 : purified metabolites from plant or microbial sources or synthetic versions of these metabolites

Common names are described in FRAC code list

M: Chemicals with Multi-Site Activity

Inorganic (electrophiles): Cu copper preparations — GROUP M01

Inorganic (electrophiles): S sulphur — GROUP M02

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

phthalimides (electrophiles): captafol, captan, folpet — GROUP M04

chloronitriles (unspecified mechanism): chlorothalonil — GROUP M05

sulphamides (electrophiles): dichlofluanid, tolylfluanid — GROUP M06

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

triazines (unspecified mechanism): anilazine — GROUP M08

anthraquinones (electrophiles): dithianon — GROUP M09

quinoxalines (electrophiles): chinomethionat — GROUP M10

maleimides (electrophiles): fluoroimide — GROUP M11

thiocarbamates (electrophiles): methasulfocarb — GROUP M12

NC : Not Specified: mineral oils, organic oils, inorganic salts, material of biological origin — GROUP NC

LEGEND

C: Respiration — MODE OF ACTION GROUP

GROUP 29 — FRAC GROUP (#)

C5: uncouplers of oxidative phosphorylation # 29 — TARGET SITE AND CODE; FRAC GROUP NAME

dinitrophenyl crotonates: binapacryl, meptyl dinocap

2,6-dinitro-aniline: fluazinam — CHEMICAL OR BIOLOGICAL GROUP; COMPOUND (ISO COMMON NAME)

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. Color coded boxes with the 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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