# FRAC Classification of Fungicides

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FRAC FUNGICIDE RESISTANCE ACTION COMMITTEE

CropLife INTERNATIONAL

## A: Nucleic Acids Metabolism

**GROUP 4**

**A1: RNA polymerase I**
# 4 PA-fungicides (PhenylAmides)

acylalanines: benalaxyl; benalaxyl-M; furalaxyl; metalaxyl; metalaxyl-M

butyrolactones: ofurace

oxazolidinones: oxadixyl

**GROUP 8**

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

bupirimate; dimethirimol; ethirimol

**GROUP 32**

**A3: DNA / RNA synthesis** (prop.)
# 32 heteroaromatics

isoxazoles: hymexazole

isothiazolones: octhilinone

imino-tosyl pyrimidinone: flumetylsulforim

**GROUP 31**

**A4: DNA topoisomerase type II (gyrase)**
# 31 carboxylic acids

oxolinic acid (bactericide)

**GROUP 52**

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

phenyl-propanol: ipflufenoquin

dihydroisoquinoline: quinofumelin

## B: Cytoskeleton and Motor Proteins

**GROUP 1**

**B1: tubulin polymerization**
# 1 MBC fungicides (= Methyl Benzimidazole Carbamates)

benzimidazoles: benomyl; carbendazim; fuberidazole; thiabendazole

thiophanates: thiophanate; thiophanate-methyl

**GROUP 10**

**B2: tubulin polymerization***
# 10 N-phenyl carbamates
*negative cross-resistance to B1

diethofencarb

**GROUP 22**

**B3: tubulin polymerization**
# 22 benzamides and thiazole carboxamides

ethylamino-thiazole carboxamide: ethaboxam

toluamide: zoxamide

**GROUP 20**

**B4: cell division (unknown site)**
# 20 phenylureas

phenylurea: pencycuron

**GROUP 43**

**B5: delocalization of spectrin-like proteins**
# 43 benzamides

pyridinylmethyl benzamides: fluopicolide; fluopimomide

**GROUP 47, 50**

**B6: actin/myosin/fimbrin function**
# 47 cyanoacrylates / # 50 aryl-phenyl-ketones

aminocyanoacrylates: phenamacril

benzophenone: metrafenone

benzoylpyridine: pyriofenone

**GROUP 53**

**B7: tubulin dynamics modulator**
# 53 pyridazine

pyridazine: pyridachlometyl

## C: Respiration

**GROUP 39**

**C1: complex I NADH oxido-reductase**
# 39 pyrimidinamines, pyrazole-MET1, quinazoline

pyrazole-5-carboxamide: tolfenpyrad

pyrimidinamine: diflumetorim

quinazoline: fenazaquin

**GROUP 7**

**C2: complex II: succinate-dehydrogenase**
# 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

**GROUP 11**

**C3: complex III cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)**
# 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

**GROUP 21**

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

sulfamoyl-triazole: amisulbrom

cyano-imidazole: cyazofamid

picolinamides: fenpicoxamid; florylpicoxamid

**GROUP 29**

**C5: uncouplers of oxidative phosphorylation**
# 29

dinitrophenyl crotonates: binapacryl; meptyl dinocap

2,6-dinitro-aniline: fluazinam

**GROUP 30**

**C6: inhibitors of oxidative phosphorylation ATP synthase**
# 30 organo tins

fentin acetate; fentin chloride; fentin hydroxide

**GROUP 38**

**C7: ATP transport (proposed)**
# 38 thiophene- carboxamides

silthiofam

**GROUP 45**

**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)

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

**GROUP 9**

**D1: methionine biosynthesis (cgs gene) (proposed)**
# 9 Anilino-Pyrimidines (AP fungicides)

cyprodinil; mepanipyrim; pyrimethanil

**GROUP 23**

**D2: protein synthesis (ribosome, termination step)**
# 23 enopyranuronic acid

blasticidin-S

**GROUP 24**

**D3: protein synthesis (ribosome, initiation step)**
# 24 hexopyranosyl antibiotics

kasugamycin

**GROUP 25**

**D4: protein synthesis (ribosome, initiation step)**
# 25 glucopyranosyl antibiotics

streptomycin (bactericide)

**GROUP 41**

**D5: protein synthesis (ribosome, elongation step)**
# 41 tetracycline antibiotics

oxytetracycline (bactericide)

**GROUP 54**

**D6: leucyl-tRNA synthetase (LeuRS)**
# 54 benzoxaboroles

tavaborole

## E: Signal Transduction

**GROUP 9**

**E1: signal transduction (mechanism unknown)**
# 13 azanaphthalenes

quinazolinone: proquinazid

aryloxyquinoline: quinoxyfen

**GROUP 12**

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

fenpiclonil; fludioxonil

**GROUP 2**

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

chlozolinate; dimethachlone; iprodione; procymidone; vinclozolin

## F: Lipid Synthesis or Transport / Membrane Integrity or Function

**GROUP 6**

**F2: phospholipid biosynthesis methyltransferase**
# 6 phosphorothiolates & dithiolanes

phosphorothiolates: edifenphos; iprobenfos; pyrazophos

dithiolanes: iso-prothiolane

**GROUP 48**

**F8: ergosterol binding**
# 48 polyene

natamycin (pimaricin)

**GROUP 28**

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

iodocarb; propamocarb; prothiocarb

**GROUP 14**

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

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

1,2,4-thiadiazole: etridiazole

**GROUP 49**

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

piperidinyl thiazole - isoxazoline: fluoxapiprolin; oxathiapiprolin

**GROUP 51**

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

polypeptide: Polypeptide ASFBIOF01-02

## G: Sterol Biosynthesis in Membranes

**GROUP 3**

**G1: C14-demethylase in sterol biosynthesis (*erg11/cyp51*)**
# 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

**GROUP 18**

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

allylamines: naftifine; terbinafine

thiocarbamates: pyributicarb (herbicide)

**GROUP 5**

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

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

piperidines: fenpropidin; dodemorph

spiroketal-amines: spiroxamine

**GROUP 17**

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

hydroxyanilides: fenhexamid

amino-pyrazolinones: fenpyrazamine

## 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

**GROUP 19**

**H4: chitin synthase**
# 19 polyoxins

peptidyl pyrimidine nucleoside: polyoxin

**GROUP 40**

**H5: cellulose synthase**
# 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

**GROUP 16.1**

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

isobenzo-furanone: fthalide

pyrrolo-quinolione: pyroquilon

triazolobenzo-thiazole: tricyclazole

**GROUP 16.2**

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

carboxamide: diclocymet

cyclopropane carboxamide: carpropamid

propionamide: fenoxanil

**GROUP 16.3**

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

tolprocarb

trifluoroethyl-carbamate

## 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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