

Mode of Action of Fungicides

FRAC classification on mode of action 2016 (www.frac.info)

A: Nucleic Acid Synthesis

A1: RNA Polymerase I
4: PA-fungicides (2-phenylamides)

A2: adenosin-deaminase
8: hydroxy 2-aminopyrimidines

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

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

B: Cytoskeleton and motor proteins

B1: β -tubulin assembly in mitosis (prop.)
1: MBC fungicides (= Methyl Benzimidazole Carbamates)

B2: β -tubulin assembly in mitosis*
10: N-phenyl carbamates

B3: β -tubulin assembly in mitosis
22 benzimidazoles and thiazole carboxamides

B4: cell division (prop.)
20 phenylfurans

B5: delocalisation of spectrin-like proteins
43 benzamides

B6: actin/myosin/filamin function e.g. in vesicle trafficking
47 cyanacrylates

C: Respiration

C1: inhibition of complex I NADH Oxido-reductase
20 pyrimidinamines pyrazole-MET1

C2: inhibition of complex II: succinate-dehydrogenase
7 SDH (Succinate Dehydrogenase) inhibitors

C3: inhibition of complex III cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene) (prop.)
11 Qo1 fungicides (Quinone Reductase Inhibitors)

C: Respiration

C4: inhibition of complex III cytochrome bc1 (ubiquinol reductase) at Q1 site
21 Q1 fungicides (Quinone Reductase Inhibitors)

C5: inhibition of complex III cytochrome bc1 (ubiquinol reductase) at Qo site (stigmatellin binding site)
45 Qo3 fungicides (stigmatellin binding site) triazole-pyrimidinamines

C6: inhibitors of oxidative phosphorylation, ATP synthase
30 organo-tins

C7: ATP production (prop.)
38 thiophene-carboxamides

C8: uncouplers of oxidative phosphorylation
23

D: Amino Acid and Protein Synthesis

D1: methionine biosynthesis (cgs gene) (prop.)
9 Amino-Pyrimidines (AP Fungicides)

D2: protein synthesis
24 enoylauronic acid

D3: protein synthesis
24 hexopyranosyl antibiotics

D4: protein synthesis
23 glucopyranosyl antibiotics

D5: protein synthesis
41 tetracycline antibiotics

E: Signal Transduction

E1: Signal transduction (mechanism unknown)
13 azanaphthalenes

E2: Osmotic signal transduction \triangleright MAP / histidine-kinase (os-2, HOG1)
12 phenylpyrroles (PP-fungicides)

E3: Osmotic signal transduction \triangleright MAP / histidine kinase (os-1, Daf1)
2 dicarboximides

F: Lipid Synthesis and Membrane Integrity

F2: phospholipid biosynthesis \triangleright methyltransferase
6 phosphorothiolates & dithiolanes

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

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

F7: cell membrane disruption (prop.)
46 plant extract

I: Melanin Synthesis in Cell Wall

I1: reductase in melanin biosynthesis
16.3 lignans (2-oxymethyl) inhibitors: Reductase (MBR)

I2: dehydratase in melanin biosynthesis
16.2 lignans (2-oxymethyl) inhibitors: Dehydratase (MBD)

I3: polyketide synthase in melanin biosynthesis
16.3 Melanin (Biosynthesis) synthase (MBP)

F7: cell membrane disruption (prop.)
46 plant extract

G: Sterol Biosynthesis in membranes

G1: C14-demethylase in sterol biosynthesis (erg11/cyp51)
3 DM-fungicides (Demethylation Inhibitors) (SBI: Class I)

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

G3: 3-Keto reductase in C4-demethylation (erg27)
17 (SBI -Class III)

G4: Squalene epoxidase in sterol biosynthesis (erg1)
18 (SBI class IV)

H: Cell Wall Biosynthesis

H4: chitin synthase
19 Polyoxins

H5: cellulose synthase
40 Carboxylic Acid Amides (C.A.A. fungicides)

P: Host Plant Defence Induction

P1: salicylic pathway
benzotriazole BTH

P2: benzothiazole

P3: thiazazole carbamate

P4: polycarboxide

P5: plant extract
Rayonaria sachalinensis (Giant Knotweed Extract)

NC : Not Classified

M: Multi Site Action

M12 inorganics

M3 dithiocarbamates & relatives

M8 triazines

M4 phthalimides

M6 sulphamides

M5 anthraquinones

M5 chionitriles

M9

M10

M11 maleimides

M7 guanidines

M2

M1

Unknown Mode of Action

27 cyanocarbonyl-oxime

33 ethyl-phosphonates

34 phosphorous acid

35 benzotriazines

36 benzene-sulfonamides

37 pyridazinones

38 thiocarbamates

39 phenyl acetamides

40 phthalic acid

41 cyfluthrin

42 thiocarbamates

43 phenyl acetamides

44 cyano-methylene thiazolidine

45 pyrimidinone-hydrazones

46 piperidinyl-thiazole isoxazoline

47 tetrazolopyrimidine

48 4-quinolyl acetate

49 cyano-methylene thiazolidine

50 pyridone

51 arylphenyl ketones

52 glycopyranosyl antibiotic

53 valdimin

Legend:

- mode of action group
- sub-group
- target site of action (where known) or positive target site (prop.)
- FRAC code no. (if any) and group name
- chemical (sub-) group

C: Respiration

C2: inhibition of complex II: succinate-dehydrogenase
7 SDH (Succinate dehydrogenase inhibitors)

thiazole carbamates

FRAC FUNGICIDE RESISTANCE ACTION COMMITTEE