



Department of
Primary Industries

Managing Fungicide Resistance

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What are fungicides?

- Chemicals that block a chemical reaction or cellular process in a fungus (or Oomycete)
- In a few cases fungicides can also stimulate plant chemical and physical defences to pathogens
- Different fungicides are grouped based on their Chemical Class (Family) and their Mode of Action (Activity Group)
- There are currently >45 Activity Groups – most based upon their Chemical Class while two additional groups are arbitrary and consist of chemicals with multi-site or unknown activities

Mode of Action of Fungicides
FRAC classification on mode of action 2017 (www.frac.info)

A: Nucleic Acid Synthesis

- A1: RNA polymerase I** (# 8: Polypyrroles (Dithienopyrimidines))
- A2: adenosin-deaminase** (# 9: Hydrazides (2-aminopyrimidines))
- A3: DNA/RNA synthesis (prop.)** (# 12: heterocyclics)
- A4: DNA polymerase type II (gyrase)** (# 17: carbonyl acids)

B: Cytoskeleton and Motor Proteins

- B1: β -tubulin assembly in mitosis** (# 1: Benzimidazoles)
- B2: β -tubulin assembly in mitosis** (# 10: Naphthyl carboxamides)
- B3: β -tubulin assembly in mitosis** (# 22: benzimidazoles and flexible carbonamides)
- B4: cell division (prop.)** (# 21: phenyls)
- B5: delocalisation of spectrin-like proteins** (# 47: isoxanthenes)
- B6: actin/myosin/fibrin function e.g. in vesicle trafficking** (# 47: isoxanthenes)

C: Respiration

- C1: inhibition of complex I: NADH Oxidoreductase** (# 3: carbonyl compounds (pyrazoles))
- C2: inhibition of complex II: succinate-dehydrogenase** (# 7: 5000: Quinone Derivatives (Quinones))
- C3: inhibition of complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)** (# 11: 1000: Quinone Derivatives (Quinones))
- C4: inhibition of complex III: cytochrome bc1 (ubiquinol oxidase) at Qi site** (# 11: 1000: Quinone Derivatives (Quinones))
- C5: uncouplers of oxidative phosphorylation** (# 27: 1000: Quinone Derivatives (Quinones))
- C6: inhibitors of oxidative phosphorylation, ATP synthase** (# 28: 1000: Quinone Derivatives (Quinones))
- C7: ATP production (prop.)** (# 29: 1000: Quinone Derivatives (Quinones))

D: Amino Acid and Protein Synthesis

- D1: methionine biosynthesis (cys gene) (prop.)** (# 1: 1000: Quinone Derivatives (Quinones))
- D2: protein synthesis** (# 21: 1000: Quinone Derivatives (Quinones))
- D3: protein synthesis** (# 24: 1000: Quinone Derivatives (Quinones))
- D4: protein synthesis** (# 24: 1000: Quinone Derivatives (Quinones))
- D5: protein synthesis** (# 24: 1000: Quinone Derivatives (Quinones))

E: Signal Transduction

- E1: signal transduction (mechanism unknown)** (# 11: 1000: Quinone Derivatives (Quinones))
- E2: osmotic signal transduction** (# 11: 1000: Quinone Derivatives (Quinones))
- E3: osmotic signal transduction** (# 11: 1000: Quinone Derivatives (Quinones))
- E4: osmotic signal transduction** (# 11: 1000: Quinone Derivatives (Quinones))
- E5: osmotic signal transduction** (# 11: 1000: Quinone Derivatives (Quinones))

F: Lipid Synthesis or Transport / Membrane Integrity or Function

- F1: phospholipid biosynthesis** (# 1: 1000: Quinone Derivatives (Quinones))
- F2: phospholipid biosynthesis** (# 1: 1000: Quinone Derivatives (Quinones))
- F3: lipid peroxidation (prop.)** (# 1: 1000: Quinone Derivatives (Quinones))
- F4: cell membrane permeability** (# 1: 1000: Quinone Derivatives (Quinones))
- F5: microbial disruptors of pathogen cell membranes** (# 1: 1000: Quinone Derivatives (Quinones))
- F6: cell membrane disruption (prop.)** (# 1: 1000: Quinone Derivatives (Quinones))
- F7: cell membrane disruption (prop.)** (# 1: 1000: Quinone Derivatives (Quinones))
- F8: ergosterol binding** (# 1: 1000: Quinone Derivatives (Quinones))
- F9: lipid homeostasis and transport** (# 1: 1000: Quinone Derivatives (Quinones))

G: Sterol Biosynthesis in Membranes

- G1: C14-demethylase in sterol biosynthesis (erg11/cyp51)** (# 3: 1000: Quinone Derivatives (Quinones))
- G2: Δ^5 -reductase and $\Delta^5 \rightarrow \Delta^7$ -isomerase in sterol biosynthesis (erg2/erg24)** (# 3: 1000: Quinone Derivatives (Quinones))
- G3: Δ^5 -reductase in C4-de-methylation (erg27)** (# 3: 1000: Quinone Derivatives (Quinones))
- G4: squalene epoxidase in sterol biosynthesis (erg1)** (# 3: 1000: Quinone Derivatives (Quinones))

H: Cell Wall Biosynthesis

- H1: chitin synthase** (# 1: 1000: Quinone Derivatives (Quinones))
- H2: cellulose synthase** (# 1: 1000: Quinone Derivatives (Quinones))

I: Melanin Synthesis in Cell Wall

- I1: reduction in melanin biosynthesis** (# 1: 1000: Quinone Derivatives (Quinones))
- I2: degradation in melanin biosynthesis** (# 1: 1000: Quinone Derivatives (Quinones))
- I3: polyketide synthase in melanin biosynthesis** (# 1: 1000: Quinone Derivatives (Quinones))

J: Host Plant Defence Induction

- J1: salicylic pathway** (# 1: 1000: Quinone Derivatives (Quinones))
- J2: jasmonic pathway** (# 1: 1000: Quinone Derivatives (Quinones))
- J3: ethylene pathway** (# 1: 1000: Quinone Derivatives (Quinones))
- J4: jasmonic pathway** (# 1: 1000: Quinone Derivatives (Quinones))
- J5: ethylene pathway** (# 1: 1000: Quinone Derivatives (Quinones))

K: Chemicals with Multi-Site Activity

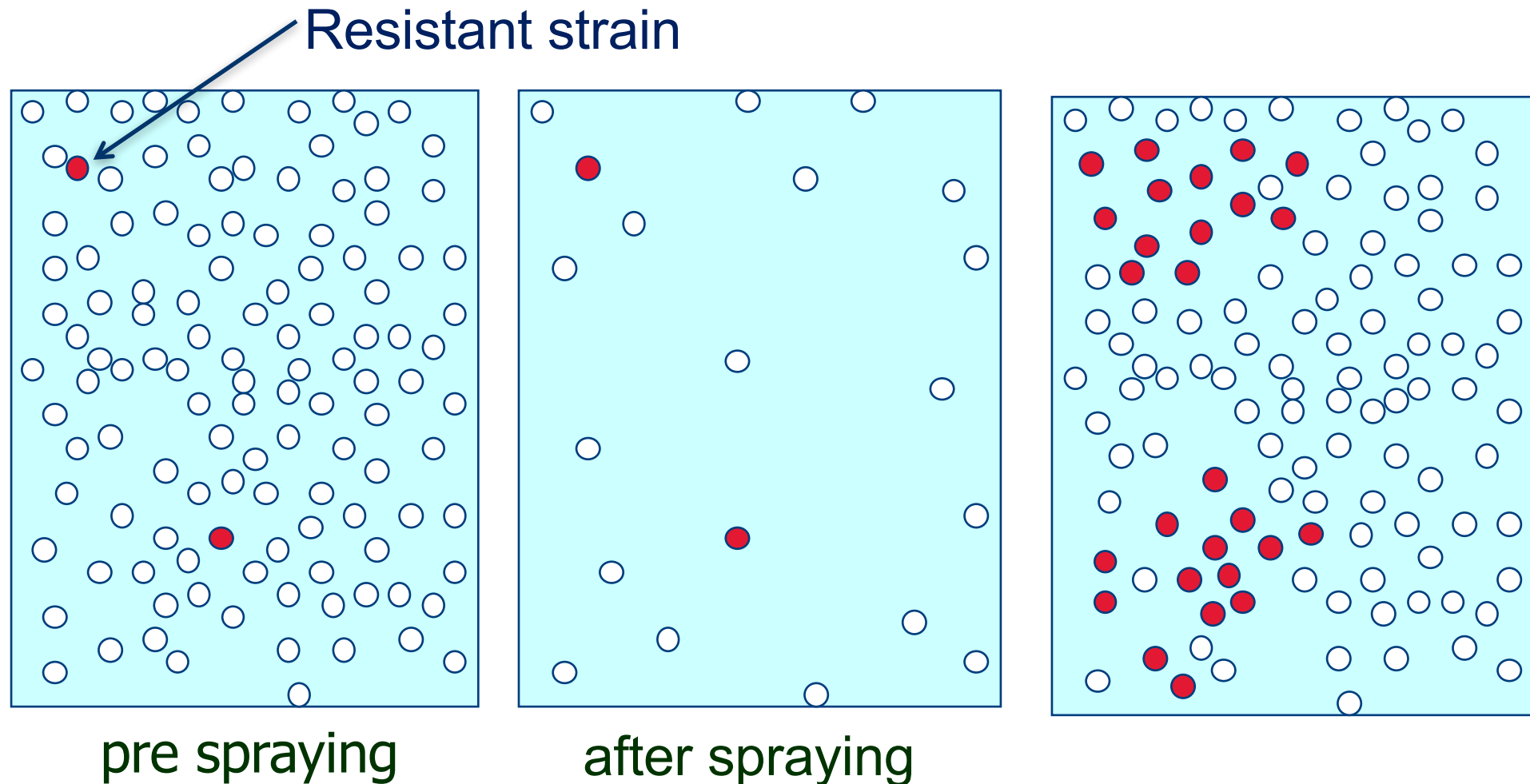
- K1: multi-site activity** (# 1: 1000: Quinone Derivatives (Quinones))
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- K44: multi-site activity** (# 1: 1000: Quinone Derivatives (Quinones))
- K45: multi-site activity** (# 1: 1000: Quinone Derivatives (Quinones))
- K46:**

What is fungicide resistance?

- Results from a change in the fungal population that makes the fungicide less effective or ineffective
- Resistant strains of the fungus are *selected* by repeated use of a particular chemical or fungicides with the same mode of action
- Resistant strains can then reproduce and increase in the fungal population
- Resistance can result from a genetic mutation or if a fungal strain can use an alternative biochemical pathway
- Resistant strains probably always exist at low frequencies in a fungal population

Resistance development

Selection of resistant mutants



Caused by increased frequency **(selection)** of resistant individuals in the fungal population

No mutation

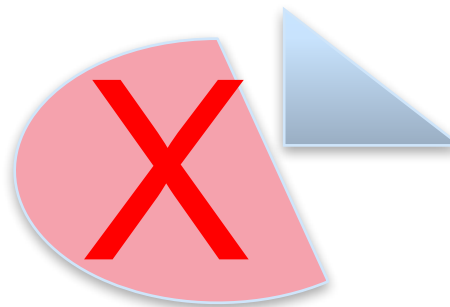
GGG GGT TTC



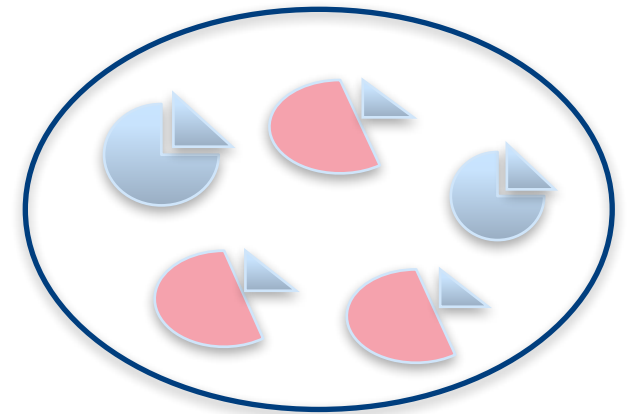
Target site: where
fungicide binds

Mutation

G**C**G GGT TTC

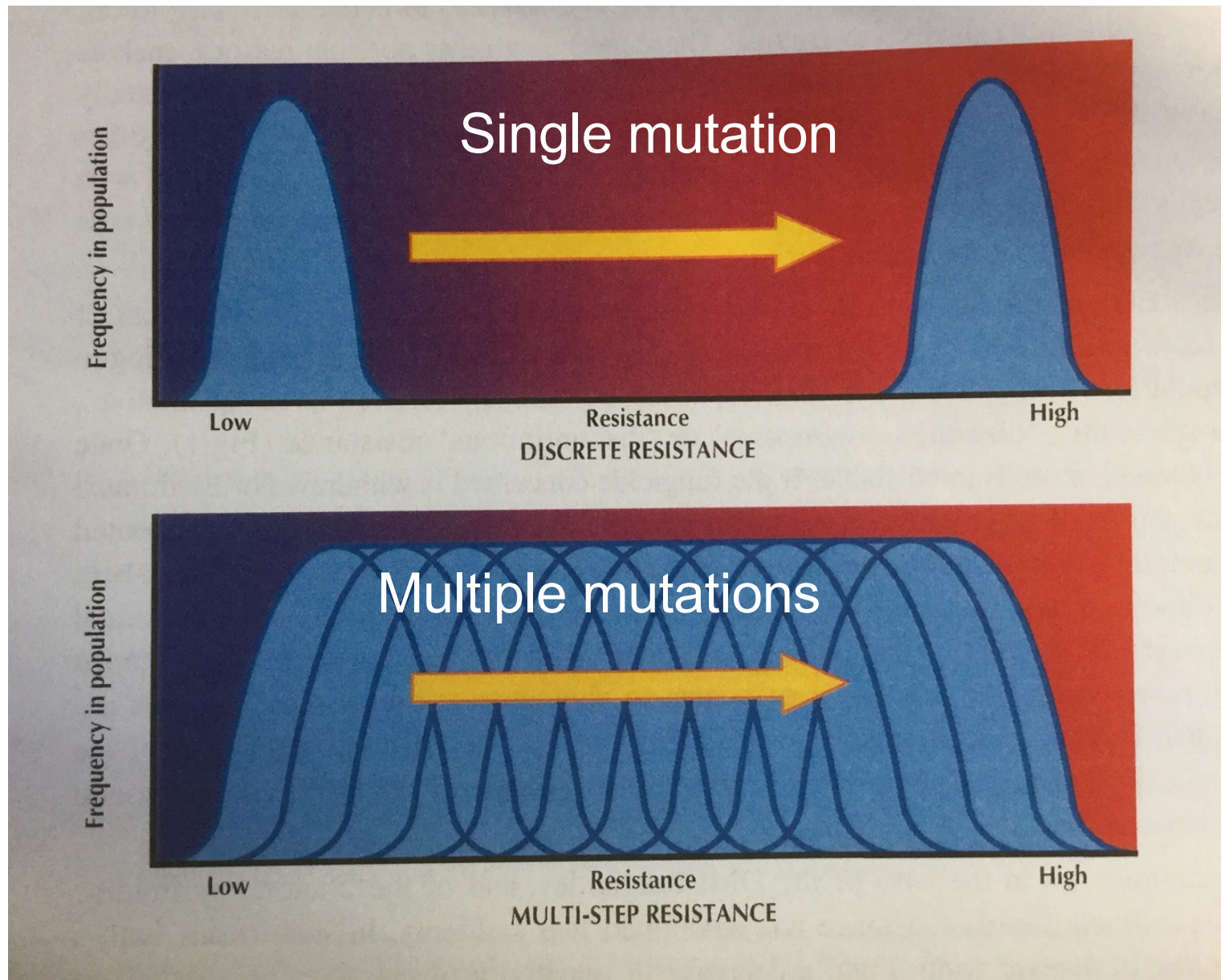


Mixed
(mutation/no
mutation)



Partial efficacy

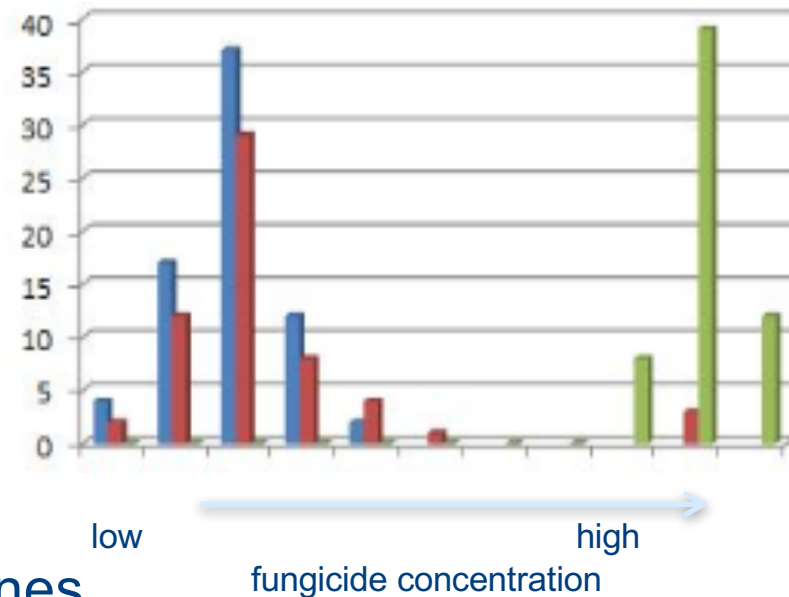
Types of resistance



Types of resistance

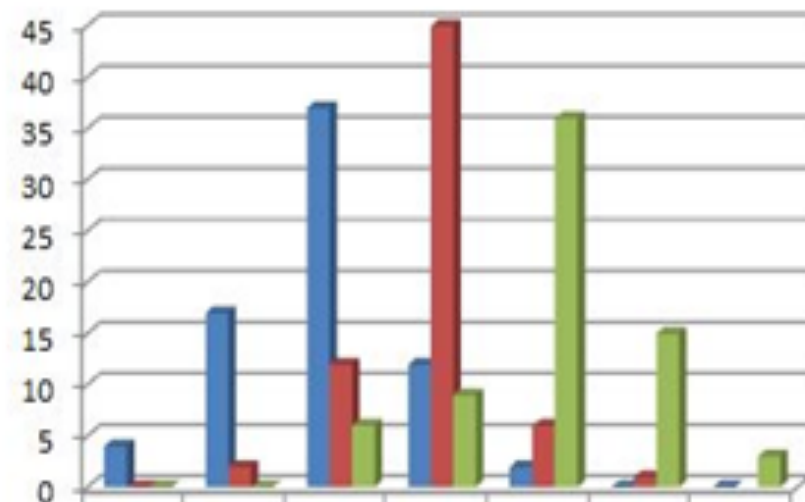
➤ Sudden loss of field control

- major or single gene
- eg. Qol, metalaxyl



➤ Gradual loss of control

- several mutations, interacting genes
- or multi genes
- eg. DMI



Estimating the risks

- Some fungicides have an inherently higher risk – binding site predisposed to genetic change &/or chemical persists on/in the plant or environment
- Pathogen produces numerous sexual and/or asexual spores
- Pathogen has multiple cycles per season
- Agronomic risks – many aspects including: chemical application practices; irrigation; fertilisers; variety selection; soil condition; crop scheduling

Detecting decreased sensitivity to fungicides

- In-vitro assays
 - Measure suppression of hyphae & spore germination
- Bioassays - biothophs
- Molecular assays
- Decreased sensitivity is not always related to field efficacy



Resistance management practices

- Limit total number of spray applications
- Apply with fungicide from different activity group
- Alternate with fungicide from different activity gp.
- Include fungicides with multi-site activity
- Use microbial biocontrols
- Apply as preventative treatments – before symptoms
- Avoid extended spray intervals
- Use preventative integrated crop management strategies: e.g. resistant varieties; crop scheduling; crop rotation; crop hygiene

Acknowledgements

- DuPont & other agrichemical companies
- FRAC resources
- Barbara Hall (SARDI)
- My friend and colleague the late Dr Trevor Wicks

Further Reading - FRAC



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