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Editors

Fungicide Resistance in Plant Pathogens

Principles and a Guide to Practical
Management

 Springer

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Chapter 17

Monitoring Resistance by Bioassay: Relating Results to Field Use Using Culturing Methods

Guido Schnabel, Meng-jun Hu, and Dolores Fernández-Ortuño

Abstract Monitoring for fungicide resistance is becoming more important in light of increased selection for resistance in key agricultural pathogens. *Botrytis cinerea*, the causal agent of gray mold of small fruits, is considered a high-risk fungus and has developed widespread resistance to multiple fungicides in many strawberry production areas managed with site-specific fungicides. Rapid determination of location-specific resistance profiles in strawberry fields allows growers to identify weaknesses in their spray program and tailor spray sequences to farm-specific needs. Growers also appreciate the educational value when participating in monitoring programs. But a monitoring program also benefits the research scientists and allows for the detection of emerging new phenotypes as well as an improved understanding of the molecular basis of resistance and the origin and spread of fungicide-resistant isolates. This information can then be used to design better resistance management strategies. Management of isolates resistant to multiple fungicides is a new challenge that will need to be addressed with an integrated approach involving the implementation of resistance management strategies at the nursery and crop producer levels.

Keywords *Botrytis cinerea* • Gray mold • Grey mould • Multifungicide resistance • Nursery • IPM • Strawberry

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- Fernández-Ortuño D, Schnabel G (2012) First report of thiophanate-methyl resistance in *Botrytis cinerea* on strawberry from South Carolina. Plant Dis 96:1700
- Fernández-Ortuño D, Chen F, Schnabel G (2012) Resistance to pyraclostrobin and boscalid in *Botrytis cinerea* isolates from strawberry fields in the Carolinas. Plant Dis 96:1198–1203
- Fernández-Ortuño D, Chen F, Schnabel G (2013) Resistance to cyprodinil and lack of fludioxonil resistance in *Botrytis cinerea* isolates from strawberry in North and South Carolina. Plant Dis 97:81–85
- Fernández-Ortuño D, Grabke A, Bryson PK, Amiri A, Li X, Peres N, Schnabel G (2014) Fungicide resistance profiles in *Botrytis cinerea* from strawberry fields of seven southern U.S. States. Plant Dis 98:825–833
- Fernández-Ortuño D, Grabke A, Li XP, Schnabel G (2015) Independent emergence of resistance to seven chemical classes of fungicides in *Botrytis cinerea*. Phytopathology 105:424–432
- Grabke A, Fernández-Ortuño D, Schnabel G (2013) Fenhexamid resistance in *Botrytis cinerea* from strawberry fields in the Carolinas is associated with four target gene mutations. Plant Dis 97:271–276
- Grabke A, Fernández-Ortuño D, Amiri A, Li X, Peres N, Smith P, Schnabel G (2014) Characterization of iprodione resistance in *Botrytis cinerea* from strawberry and blackberry. Phytopathology 104:396–402
- Ishii H, Yano K, Date H, Furuta A, Sagehashi Y, Yamaguchi T, Sugiyama T, Nishimura K, Hasama W (2007) Molecular characterization and diagnosis of QoI resistance in cucumber and eggplant fungal pathogens. Phytopathology 97:1458–1466
- Li XP, Fernández-Ortuño D, Chen S, Grabke A, Luo CX, Bridges WC, Schnabel G (2014a) Location-specific fungicide resistance profiles and evidence for stepwise accumulation of resistance in *Botrytis cinerea*. Plant Dis 98:1066–1074
- Li XP, Fernández-Ortuño D, Grabke A, Schnabel G (2014b) Resistance to fludioxonil in *Botrytis cinerea* isolates from blackberry and strawberry. Phytopathology 104:724–732
- Oliveira MS, Peres NA (2013) The role of nursery plants as a potential source of inoculum for *Botrytis cinerea* and its impact on fungicide sensitivity. Phytopathology:S214-P
- Oliveira MS, Peres NA (2014) Strawberry nursery plants as a source of *Botrytis cinerea* isolates resistant to fungicides. Phytopathology:S208-P
- Schnabel G, Bryson PK, Bridges W, Brannen PM (2004) Reduced sensitivity in *Monilinia fructicola* to propiconazole in Georgia and implications for disease management. Plant Dis 88:1000–1004
- Schnabel G, Amiri A, Brannen PM (2012) Field kit- and internet-supported fungicide resistance monitoring. In: Thind TS (ed) Fungicide Resistance in Crop Protection: Risk and Management. CAB International, Oxfordshire, pp 116–132
- Sierotzki H, Scalliet G (2013) A review of current knowledge of resistance aspects for the next-generation succinate dehydrogenase inhibitor fungicides. Phytopathology 103:880–887
- Sutton JC (1998) Botrytis Fruit Rot (Gray Mold) and blossom blight. In: Maas JL (ed) Compendium of strawberry diseases. APS Press, St. Paul, p 28
- Sutton JC, Peng G (1992) Biocontrol of *Botrytis cinerea* in strawberry leaves. Phytopathology 83:615–621
- Wade M (1988) Strategies for preventing or delaying the onset of resistance to fungicides and for managing resistance occurrences. In: Delp CJ (ed) Fungicide resistance in North America. APS Press, St. Paul, pp 14–15
- Weber RWS, Hahn M (2011) A rapid and simple method for determining fungicide resistance in *Botrytis*. J Plant Dis Prot 118:17–25