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New generation fungicides: a paradigm shift in fungal disease management

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Abstract

Fungi cause significant diseases in horticultural crops, causing economic loss. Fungicides are used to manage these infections, but new generation fungicides have improved disease management due to their novel mode of action, site specificity, and minimal effect on non-target organisms. Various formulations available today ensure the maximum effectiveness and even distribution of active ingredients across the region of application. To ensure food safety, countries monitor fungicide residue levels in domestic and imported foods. Technological advances can improve plant uptake and reduce fungicide toxicity.

Key words: New generation molecules, mode of action, Fungicide resistance, Fungicide residue

Introduction

Horticultural crops can help feed the world's 9 billion people by 2050 and improve their health and livelihoods. They also reduce hunger, malnutrition, and obesity. However, they are vulnerable to various pests and diseases that affect their quality, cost, and environmental impact. New fungicides are being tested to control these problems, but their effectiveness is still uncertain. Fungal diseases affect many horticulture crops, such as tomato wilt, BSR in oil palm, onion downy mildew, and others. They cause environmental, economic, and social problems, and global losses of 2,000 billion dollars. Plant protection can increase farmers' income by ₹ 70,000 crore per year. The main challenges in the management of fungal diseases are Lack of durable resistance, changing disease scenario and evolution of plant pathogen as well as evolution of fungicide resistance. They have improved from the old Bordeaux mixture to modern, eco-friendly, and specific ones. New fungicides need features like curative, long-

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lasting, and systemic effects. Natural and synthetic compounds are tested for their performance and safety. These fungicides can enhance disease control and environmental care. To develop and market fungicides, environmental safety is crucial. Molecules that are harmless to humans, non-target organisms, and the environment are sought by researchers. They avoid cancer, soil pollution, and food chain accumulation. New generation fungicides with different modes of action are required to meet the EU's (European Union) plant protection standards and enhance disease control **(Ishii *et al*., 2011).**

Classification and mode of action of new generation fungicides

The fungicide industry is constantly developing new fourth-generation fungicides, offering broad activity, site-specific action, and environmental safety. However, resistance against these fungicides is clear. FRAC monitors resistance and classifies fungicides based on modes of action for better disease management and minimizing field resistance. Some important new generation fungicides are grouped based on their importance in agriculture use. Some fungicides stop the energy production in mitochondria. These are QoIs (strobilurins) and they have different types. For example, azoxystrobin, picoxystrobin and fluoxastrobin. Botrytis cinerea is not affected by QoIs and can resist all of them **(Markoglou *et al*., 2006).** Cyanoimidazole and sulfamoyl-triazole fungicides also stop the energy production. These are cyazofamid and amisulbrom. They can be resisted by *Phytophthora capsici*. Another group is 2,6-dinitroanilines, such as fluazinam. They can be resisted by *Botrytis cinerea* too (Kousik and Keinath, 2008).The anilinopyrimidines (AP fungicides) block a pathway to make methionine. These are cyprodinil, pyrimethanil and mepanipyrim. They can be resisted by *Botrytis cinerea* and *Venturia inaequalis*.The benzamides and thiazole carboxamides disrupt the cell division process. These are zoxamide, ethaboxam, fluopicolide and fluopimomide. They can be resisted by *Phytophthora capsici* and other pathogen. The C14-reductase and C8→ C 7- isomerase in sterol biosynthesis (erg24, erg2) in sterol biosynthesis (erg24, erg2) are blocked by amines (morpholines) and spiroketalamines, such as spiroxamine. They have low to moderate resistance risk against various pathogens. Cell wall synthesis inhibitors stop fungi from making their cell walls. They are fungicides called CAAs (Carboxylic Acid Amides). CAAs have three types: cinnamic acid amides, valinamide carbamates, and mandelic acid amides. They have different target sites and activity ranges. Dehydratase inhibitors stop fungi from making melanin. They are fungicides in the MBI-D group. They have three types: cyclopropane-carboxamide, carboxamide, and propionamide. They have different target sites and activity ranges.

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Formulations and delivery mechanisms

Fungicides are manufactured as technical materials that are then processed into formulations to ensure the maximum effectiveness and even distribution of active ingredients across the region of application. Each formulation has its own unique qualities. New technologies have improved fungicide safety and efficiency. Microencapsulation, water soluble bags, and nano-formulations reduce toxic ingredients and waste. They also enhance controlled release, dosage, intervals, and environmental risks. Nanoparticles increase surface area and penetration. Nano-formulations have better properties and no residues. Slow release boscalid controls grey mold diseass. Fungicides are mainly delivered through seed treatment, foliar application, soil drenching, trunk injection, root feeding, chemigation, wound dressing & pasting and crown drenching depending up on the type of crop and mode of transmission of the pathogen.

Problem of fungicidal residues in agricultural products

Fungicides are effective against fungal diseases in horticultural crops, but indiscriminate application can lead to residue accumulation in crop produce, causing health issues for consumers. To ensure food safety, countries monitor fungicide residue levels in domestic and imported foods. The Codex Committee on Pesticide Residues recommends maximum residue limits (MRL) for pesticides in foodstuffs, including new generation fungicides like Strobilurins. However, the harmful residual effect on human health is still unknown, leading to countries and international organizations setting MRLs for strobilurins in food and agricultural products. Fungicide residue detection requires sensitive, rapid, and reliable technologies. Various detection techniques provide reliable data for government departments to use for reference. These data help to identify the types and levels of fungicide residues and support production control, market supervision, standard revision, and risk assessment (Qin et al., 2021). Therefore, it is necessary to establish effective and simple detection methods for fungicide levels. Some reported methods include GC, GC-MS, HPLC, HPLC-MS, LC-MS, biosensors, spectrophotometry, and capillary electrophoresis. LIF and SERS are emerging technologies with high sensitivity and simple synthesis that can detect low dose fungicides in real samples.

Fungicide resistance and management

Fungicides are crucial in treating fungal diseases, but resistance has increased due to the introduction of systemic fungicides. This has threatened the efficacy of fungicide-based management, as resistance evolution is a continuous process. Modern fungicides, often referred to as'single-site' or'site-specific' fungicides, work on a single target site, making them less sensitive to gene mutations. Older fungicides like copper and chlorothalonil have minimal risk of developing resistance. Resistance mechanisms vary depending on the mode of action, including alteration to the target site, reduced fungicide uptake, active export outside fungal cells, and fungicide detoxification or metabolic breakdown. New generation fungicides also exhibit these mechanisms. The major mechanism of fungicide resistance include altered target site, reduced fungicide uptake, Active fungicide export and Fungicide detoxification. For instance, Fungal cells can break down or detoxify foreign compounds like fungicides by changing their chemical groups and excreting or removing them. For example, a CYP684 enzyme in B. pseudocinerea oxidizes fenhexamid and makes it resistant. Another fungicide, kresoxim-methyl, is also detoxified by some fungi. Fungicides help control plant diseases, but they also select for resistant fungal mutants. When these mutants dominate the population, the fungicide becomes ineffective

Fungicide resistance management is vital for crop production efficiency. To prevent or manage resistance in plant pathogens, strategies include reducing single-site fungicide use, avoiding high-risk fungicides, and delaying resistance emergence. GIFAP's FRAC committee addresses resistance issues and promotes cooperative efforts. The following practices can lower the fungicide risk:

- Use different types of fungicides in mixtures or rotations.
- Use compounds that reduce selection pressure as companions or partners.
- Limit the number of fungicide treatments per season.
- Follow the label instructions and doses recommended by the manufacturer.
- Use fungicides with negative cross resistance to decrease resistant isolates.

Conclusion

There are a variety of protocols for treating fungal diseases, but fungicides remain at the forefront of these therapies and have the potential to inhibit pathogenic fungi and their negative effects. Right pesticide at right time in right dose with right compatible compounds in right mixing order, right calibration with respect to volume per hectare should be practiced for managing fungicidal resistance. Establishment of effective and simple fungicide residue detection methods to closely monitor the fungicide levels is necessary. The current trend to develop safer fungicides is highly tactical with efficient application technologies can increase the quality of horticultural produce with less pesticide residues.

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