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Responsible Use of Fungicide for Sustainable Crop Protection

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Fungal diseases are a major threat to crop production, and fungicides play a vital role in protecting the crops from yield and quality losses. However, concerns about fungicide residues, food safety, environmental impacts, and resistance have raised questions about their use. This article discusses the importance of fungicides, their types, modes of action, residue management, and resistance management, while emphasizing the need for their responsible use within an Integrated Disease Management (IDM) approach. By addressing common misconceptions and consumer concerns, the article highlights that fungicides, when used judiciously and in accordance with recommended guidelines, remain indispensable tools for sustainable crop protection and safe food production.

Keywords: Fungicides, Crop protection, FRAC, Fungicide resistance, Integrated Disease Management

Introduction

Fungal diseases are silent enemies of agriculture. More than 80% of plant species are susceptible to diseases caused by fungal pathogens, and disease outbreaks can result in substantial losses in crop yield and quality, with serious challenges for food security and farmers' livelihoods (Tian et al., 2020). Protecting crops from these diseases is essential, and fungicides have become one of the most effective tools available to farmers. Despite their importance, fungicides are often viewed with suspicion. Many consumers hesitate before buying fruits and vegetables, wondering whether they contain harmful chemical residues, whether they are safe to eat, or if washing is enough to remove any remaining fungicides. These concerns are understandable and deserve attention. However, fungicides are neither inherently harmful nor a universal solution. The problem arises when they are misused or overused. In many farming communities, limited access to technical information, adequate training, and extension services can sometimes lead to incorrect doses, inappropriate timing, or repeated applications of fungicides. Therefore, the outcome depends not only on the fungicide itself but also on how farmers understand and use it. So, are fungicides friends or foes? The answer depends largely on how responsibly and judiciously they are used.

Fungicides

Fungicides are natural or synthetic products used to protect plants from diseases caused by fungi and fungi-like organisms. They act by preventing infection, suppressing fungal growth, or controlling existing infections. Fungicides include both conventional chemical products and biological agents, such as beneficial microorganisms, which help to manage fungal diseases (Oliver & Beckerman, 2022). Their importance lies in protecting crops from destructive diseases that can spread rapidly under favorable conditions. Diseases such as blights, rusts, mildews, anthracnose, and wilts can cause severe reductions in crop yield, quality, and farmers' income. For instance, late blight can rapidly devastate potato and tomato

crops under cool and humid conditions. By minimizing such losses, fungicides play a vital role in ensuring crop productivity, food security, and sustainable agricultural production.

Fungicide residues

After a fungicide is applied, small amounts may remain on or within fruits, vegetables, or other harvested produce. These are known as fungicide residues. Their presence does not necessarily make food unsafe. When fungicides are applied according to approved recommendations, including the correct dose and the prescribed pre-harvest interval (PHI), residue levels are expected to remain within the Maximum Residue Limits (MRLs) established for food commodities (FSSAI, 2022). Concerns generally arise when fungicides are misused, such as through excessive application, unnecessary repeat sprays, or harvesting the crop before the PHI is complete. Therefore, following label instructions and observing the recommended PHI are essential for producing safe food while ensuring effective disease management.

Types of Fungicide

Fungicides are broadly classified into two categories: contact and systemic fungicides. Contact fungicides remain on the plant surface, forming a protective barrier that prevents fungal pathogens from infecting the plant. They are not absorbed, so they work best when applied before infection and may need to be reapplied after heavy rainfall. Common examples include mancozeb, copper oxychloride, and chlorothalonil. In contrast, systemic fungicides are absorbed by the plant and move within its tissues, allowing them to protect new growth and suppress infections during their early stages. Examples include difenoconazole, azoxystrobin, carbendazim, and metalaxyl. Both contact and systemic fungicides have distinct advantages, and selecting the appropriate type depends on the crop, the disease being managed, and the recommended application guidelines.

How fungicides work

Fungicides protect plants by interfering with the essential life processes of disease-causing fungi and fungus-like organisms, preventing them from infecting plants, growing, or reproducing. As a result, the pathogen is unable to establish or spread within the plant, slowing or stopping disease development and protecting crop yield and quality. The specific way in which a fungicide affects a pathogen is known as its mode of action. Depending on their mode of action, fungicides may:

1. Prevent spore germination and infection.
2. Inhibit the growth and spread of the fungus
3. Disrupt or block energy production required for fungal survival
4. Interfere with cell membrane or cell wall formation.

FRAC groups

Not all fungicides work in the same way. The Fungicide Resistance Action Committee (FRAC) classifies fungicides based on their mode of action and assigns each group a unique FRAC code. Fungicides within the same FRAC group are classified according to their mode of action and cross-resistance pattern. Repeated use of products from the same FRAC group can allow resistant strains of the pathogen to survive and multiply, reducing the fungicide's effectiveness over time. Using fungicides according to their FRAC group, resistance risk, recommended doses and appropriate resistance-management practices can help reduce the risk of fungicide resistance (FRAC, 2026).A few important FRAC groups are shown below :

FRAC Groups	Mode of Action	Examples
1	MBC–Methyl Benzimidazole Carbamates; tubulin polymerization	Carbendazim
3	DMI – Demethylation Inhibitors; sterol biosynthesis	Difenoconazole, Propiconazole

FRAC Groups	Mode of Action	Examples
4	PhenylAmides; RNA polymerase I	Metalaxyl
11	QoI – Quinone outside Inhibitors; respiration	Azoxystrobin, Pyraclostrobin
M	Multi-site activity	Mancozeb (M03),Copper fungicides (M01)

Source: FRAC (2026)

Common mistakes in fungicide use

The effectiveness of the fungicide depends on how the product is used rather than the product itself. Even the most effective fungicide may fail if it is applied incorrectly. Some of the most common mistakes that reduce the effectiveness of the fungicide include:

1. Spraying without correctly diagnosing the disease.
2. Using higher amounts than the recommended doses.
3. Repeatedly using fungicides from the same FRAC group.
4. Spraying too early or waiting until the disease is well established.
5. Ignoring label instructions and the pre-harvest interval (PHI).
6. Mixing products without checking their compatibility.

The key to successful disease management is simple, i.e., use the right fungicide, against the right disease, at the right dose, and at the right time. Fungicides should not be applied simply because the calendar says it is time to spray. Instead, applications should be guided by regular crop scouting, disease risk, weather conditions, disease forecasting, and expert recommendations. This approach not only improves disease control but also reduces unnecessary applications, lowers production costs, and helps delay the development of fungicide resistance.

Responsible Use of Fungicide

Responsible fungicide use begins with the correct diagnosis of the disease to ensure that the pathogen can be effectively controlled by the selected fungicide. Fungicides should always be applied at the recommended dose, as excessive amounts do not improve disease control but can increase production costs, residue levels, and the risk of resistance. To preserve their effectiveness, fungicides with different FRAC groups should be rotated rather than repeatedly using products with the same mode of action (Yin et al., 2023). The timing of application is equally important, as many fungicides provide the best protection when applied during the early stages of infection. Proper sprayer calibration is essential to achieve uniform coverage and accurate application. In addition, the recommended pre-harvest interval (PHI) should always be observed to allow residue levels to decline to safe limits before harvest.

Integrated Disease Management

Most importantly, fungicides should be used as a component of an Integrated Disease Management (IDM) programme rather than a sole method of disease control. IDM is a holistic approach that combines different disease-management strategies to keep disease below economically damaging levels while reducing unnecessary dependence on fungicides. A fungicide should be viewed as one player on a team, not the entire team. No fungicide can provide sustainable disease control on its own. An effective IDM programme begins with correct disease diagnosis and regular field monitoring. Farmers should identify the disease and assess its severity before deciding whether a fungicide application is necessary. Preventive measures such as the use of resistant or tolerant varieties, healthy and disease-free planting material, proper field sanitation, removal of infected plant debris, and control of alternative hosts can reduce the initial amount of disease-causing inoculum. Cultural practices, including appropriate plant spacing, balanced fertilizer application, proper irrigation and drainage, crop rotation where applicable, and timely removal of infected plant parts, can further create conditions that are less favourable for disease development.

Biological control can also contribute to IDM through the use of beneficial microorganisms such as *Trichoderma* spp. and beneficial bacteria that suppress pathogens through competition, antibiosis, mycoparasitism, or induction of plant defence responses. These approaches can complement chemical fungicides and may help reduce the frequency of fungicide applications. Fungicides remain an important component of IDM when disease pressure exceeds manageable levels or when other measures alone are insufficient. However, their use should be need-based and guided by disease risk, weather conditions, crop stage, disease severity, and disease forecasting where available. Selecting fungicides with appropriate modes of action and integrating them with non-chemical methods can improve disease control while reducing selection pressure for fungicide resistance. Therefore, IDM is not about completely eliminating fungicides; rather, it is about using fungicides more strategically and combining them with preventive, cultural, biological, and host-based approaches. This integrated approach can improve the reliability and sustainability of disease management, reduce unnecessary pesticide use, lower production costs, and help preserve the effectiveness of available fungicides.

Myths and facts

Several misconceptions surround the use of fungicides, often leading to their misuse or unnecessary fear. A common belief is that applying more fungicide or spraying more frequently will provide better disease control. In reality, excessive or unnecessary applications increase production costs, leave higher residue levels, and accelerate the development of fungicide resistance without improving effectiveness. Another misconception is that a single fungicide can control every plant disease or that all fungicides work in the same way. In fact, fungicides differ in their target pathogens and modes of action, making accurate disease diagnosis and the selection of the appropriate fungicide essential. Some people also believe that fungicides are always harmful or that they can cure any disease once symptoms appear. However, when used according to recommended guidelines, fungicides are valuable tools for protecting crops, and many are most effective when applied before infection or during the early stages of disease development. Understanding these facts helps farmers use fungicides more responsibly while ensuring effective and sustainable disease management.

Consumer awareness

Consumers can also take simple steps to improve food hygiene and reduce exposure to fungicide residues. Fungicide residues in food are regulated through established safety limits, and consumers can further reduce residues through appropriate food preparation practices.

1. Wash fruits and vegetables thoroughly under clean running water before consumption.
2. Remove damaged, diseased, or rotten portions of fruits and vegetables before eating and preparing food.
3. Peel fruits and vegetables such as cucumbers, carrots, or apples when appropriate, recognizing that peeling may also remove some nutrients.
4. Follow the recommended pre-harvest interval (PHI) for treated crops rather than consuming produce immediately after fungicide application.
5. Avoid using soap, detergent, or household disinfectants to wash fruits and vegetables; clean running water is recommended.

It is important to remember that washing helps reduce surface residues, but it may not completely remove systemic fungicides that have been absorbed into plant tissues. The effectiveness of washing or peeling varies depending on the fungicide, the type of produce, and the processing method (Chung, 2018). Following proper food preparation practices, together with the responsible use of fungicides by farmers, helps ensure that fresh produce remains safe and nutritious.

Conclusion

Fungicides are neither friends nor foes; they are valuable tools whose benefits depend on how wisely and responsibly they are used. When applied according to recommended guidelines, they protect crops from devastating diseases, reduce yield and quality losses, support farmers' livelihoods, and contribute to a safe, nutritious, and sustainable food supply. However, their indiscriminate use can lead to fungicide resistance, unnecessary residues, and environmental concerns, highlighting the importance of responsible disease management. For consumers, the key is awareness rather than fear. The presence of fungicide residues does not necessarily mean that food is unsafe. When farmers follow recommended application rates and observe the prescribed pre-harvest interval (PHI), fungicide residues can be managed within established regulatory limits. Simple practices such as washing fruits and vegetables thoroughly under running water, removing damaged or diseased portions, and maintaining good food hygiene can further help reduce surface residues and improve food safety. As agriculture moves towards a more sustainable future, fungicides should be viewed as one component of an integrated approach to crop protection rather than a standalone solution. The goal is not to use more fungicides, but to use them wisely and only when they are truly needed. By combining scientific knowledge, responsible farming practices, and informed consumer choices, we can protect crops, safeguard public health, support farmer livelihoods, and build a more resilient and sustainable agricultural future.

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