



Microbiome Armour: Using Beneficial Microbes to Fight Both Pests and Pathogens

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INTRODUCTION

Agriculture is facing a double challenge: protecting crops from insect pests and preventing diseases caused by fungi, bacteria and other pathogens. Traditionally farmers have relied heavily on chemical pesticides and fungicides to manage these threats. However excessive or inappropriate pesticide use can contribute to resistance development, environmental contamination and harm to beneficial organisms. The need for sustainable crop protection has therefore increased interest in beneficial microorganisms that can strengthen plant health and suppress harmful organisms.

Imagine a protective shield around a crop, built not from chemicals but from living microorganisms. This is the idea behind “microbiome armour” — the use of beneficial bacteria fungi and other microorganisms associated with plants and soil to improve crop defence against pests and pathogens. These microbes can compete with harmful organisms, produce protective compounds, stimulate plant defence mechanisms and improve root health. Some can also influence insect behaviour and plant responses to herbivore attack (Woo et al., 2023; Chaudhary *et al.*, 2024). The concept is closely connected to the plant microbiome: the community of microorganisms living on and inside plants and around their roots. By understanding and managing these microbial communities scientists are exploring new ways to protect crops while reducing dependence on conventional pesticides.

What is microbiome armour?

The plant microbiome includes bacteria fungi and other microorganisms that inhabit the rhizosphere (the soil surrounding roots), the phyllosphere (above-ground plant surfaces) and internal plant tissues.

Some microorganisms are harmful but many are beneficial or harmless. Beneficial microbes can help plants acquire nutrients tolerate environmental stress and defend themselves against pests and diseases. Microbiome armour does not mean that every microorganism is protective. Instead it involves selecting useful microbial strains or managing microbial communities to provide reliable benefits to crops. The effectiveness of these microbes

depends on the crop species, microbial strain, soil conditions and environmental factors.

How do beneficial microbes protect crops?

Beneficial microbes use several mechanisms to protect plants. Some act directly against insect pests or disease-causing organisms while others strengthen the plant's own defence system. In certain cases a single microbial strain may contribute to more than one protective function.

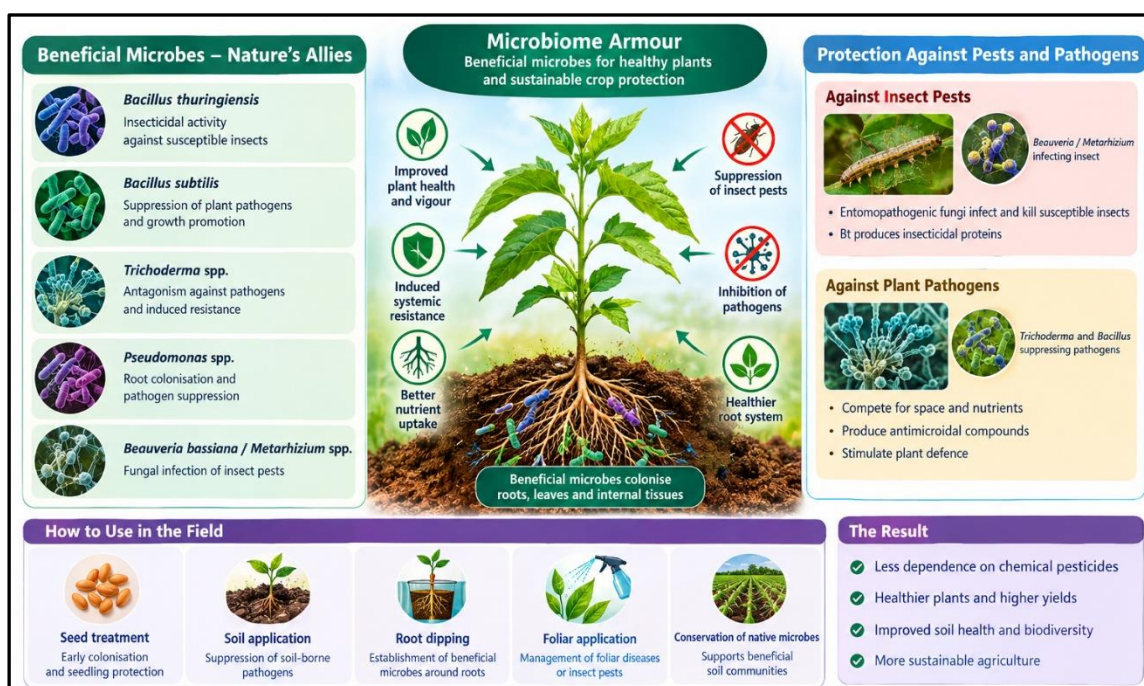


Figure: Beneficial microbes as a natural shield: how they protect plants from insect pests and pathogens and can be used in crop production.

Table 1: Major mechanisms of microbiome armour

Protective mechanism	How it works	Potential benefit
Competition	Beneficial microbes compete for space and nutrients	Limits the establishment of harmful microorganisms
Antibiosis	Microbes produce substances that inhibit susceptible pathogens	Reduces disease development
Mycoparasitism	Certain fungi attack and parasitise other fungi	Suppresses some fungal plant pathogens
Induced resistance	Microbes stimulate plant defence pathways	Helps plants respond more effectively to later attacks
Insect pathogenicity	Certain bacteria and fungi infect or kill susceptible insect pests	Reduces pest populations
Improved plant vigour	Microbes support nutrient uptake and root development	Helps plants withstand damage and environmental stress

These mechanisms may operate together, although their contribution varies among microbial strains and crop systems (Woo *et al.*, 2023; Collinge *et al.*, 2022).

Beneficial microbes that act as natural bodyguards

1. Bacillus: The bacterial shield

Species of *Bacillus* are among the most widely studied beneficial bacteria in agriculture. Certain strains of *Bacillus subtilis* and related species can suppress plant pathogens through antimicrobial compounds, competition and stimulation of plant defence. *Bacillus thuringiensis* (Bt) is especially important for insect pest management because selected strains produce insecticidal proteins that act against susceptible insects. Research is also exploring how some *Bacillus* strains can support plant growth while contributing to the suppression of both pests and pathogens. However, these functions are strain-specific and should not be assumed for every member of the genus (Gomis-Cebolla *et al.*, 2023).

2. Trichoderma: The fungal protector

Trichoderma is a beneficial fungal genus commonly studied for biological control of plant diseases. It can colonise the root zone and compete with harmful fungi for nutrients and space. Some species attack other fungi through mycoparasitism and produce enzymes that damage their cell walls. In addition to direct

antagonism *Trichoderma* can stimulate plant defence responses and improve root development. These properties make it a valuable component of integrated crop protection programmes (Woo *et al.*, 2023).

3. Pseudomonas: The root-zone defender

Certain beneficial *Pseudomonas* strains colonise the rhizosphere and help suppress soil-borne pathogens. Depending on the strain they may produce antimicrobial compounds, compete for iron through siderophores or stimulate plant defence responses. Their protective value depends on their ability to establish in the root zone and remain active under field conditions. Careful selection of compatible strains is therefore essential.

4. Beauveria and Metarhizium: Fungi that attack insect pests

Unlike microbes that primarily suppress plant diseases, entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium* species can infect susceptible insects. Their spores attach to the insect cuticle, germinate and penetrate the body under suitable conditions. The resulting infection may cause insect death. These fungi can be valuable against selected insect pests in crops when the strain, formulation and application method are appropriate. Their effectiveness is influenced by temperature, humidity, sunlight and the insect's susceptibility.

Table 2: Beneficial microbes and their potential roles in crop protection

Beneficial microorganism	Primary protective role	Examples of potential applications
<i>Bacillus thuringiensis</i>	Insecticidal activity against susceptible insects	Management of selected caterpillars and other target pests
<i>Bacillus subtilis</i>	Suppression of certain plant pathogens	Management of selected fungal and bacterial diseases
<i>Trichoderma</i> spp.	Antagonism against plant pathogens and induced resistance	Management of selected soil-borne diseases
<i>Pseudomonas</i> spp.	Root colonisation and pathogen suppression	Protection against selected root diseases
<i>Beauveria bassiana</i>	Fungal infection of susceptible insects	Biological control of selected insect pests
<i>Metarhizium</i> spp.	Fungal infection of susceptible insects	Management of selected agricultural insect pests

Can one microbial system fight both pests and pathogens?

One of the most promising aspects of microbiome-based crop protection is the possibility of obtaining multiple benefits from a carefully designed microbial treatment. A beneficial microorganism may suppress a disease-causing fungus while also improving the plant's defence against insect herbivores. Other approaches combine compatible microbial strains that perform different functions.

For example, a crop protection programme may use a suitable *Trichoderma* strain to suppress a soil-borne fungal pathogen alongside an approved entomopathogenic fungus to target a susceptible insect pest. A compatible bacterial inoculant may provide additional root-zone protection. However, a combination of microbes is not automatically more effective than a single strain. Microorganisms can compete with each other or fail to survive in the same formulation. Their compatibility and performance must be tested before they are combined in commercial products or field applications (Poveda & Eugui, 2023)

The role of the plant's own defence system

Plants are not passive victims of insect attacks or pathogen infections. They possess defence

mechanisms that can be activated by beneficial microorganisms. This process is often described as induced resistance or defence priming.

When certain beneficial microbes colonise plant roots or tissues they can stimulate signalling pathways involved in defence. As a result, the plant may respond more effectively when attacked by an insect or exposed to a pathogen. Depending on the interaction this response can involve defence-related enzymes, signalling molecules and changes in protective compounds.

Some beneficial microbes also alter the nutritional quality or chemical composition of plants which may influence insect feeding and development. However, these effects vary across plant–microbe–insect combinations and require careful evaluation (Pineda *et al.*, 2017).

How can farmers use microbiome armour?

Microbiome-based crop protection can be incorporated into integrated pest management (IPM). Rather than replacing every existing crop protection measure, beneficial microbes can complement resistant varieties, crop rotation, field sanitation, pest monitoring and the conservation of natural enemies.

Table 3: Practical ways to incorporate beneficial microbes into crop production

Application method	How it is used	Main objective
Seed treatment	Applying a suitable microbial formulation to seeds	Early root colonisation and seedling protection
Soil application	Applying selected microbes to soil or the root zone	Suppression of selected soil-borne pathogens
Root dipping	Treating seedling roots before transplanting	Establishment of beneficial microbes around roots
Foliar application	Spraying an appropriate microbial product on plant surfaces	Management of selected foliar diseases or insect pests
Conservation of native microbes	Maintaining organic matter and avoiding unnecessary disturbance	Supporting beneficial soil microbial communities

The application method must match the microbial product and its intended target. Farmers should follow the product label for dose, timing, storage and compatibility with other agricultural inputs.

Challenges: Building a reliable living shield

Despite its potential microbiome armour faces several practical challenges. Beneficial microorganisms may perform well in laboratory conditions but show inconsistent results in farmers' fields because of changes in temperature, moisture, soil properties and microbial competition. Some formulations also lose viability during storage or transport.

Other challenges include limited awareness among farmers, variable product quality and insufficient field validation for particular crops and regions. Broad-spectrum pesticides may also harm beneficial microorganisms or reduce the survival of microbial products when incompatible treatments are used. To overcome these limitations researchers, need to develop stable formulations, identify compatible microbial combinations and test their effectiveness across different locations and seasons. Quality control and appropriate regulatory oversight are equally important for ensuring product safety and reliability (Collinge *et al.*, 2022).

Future prospects: From microbial products to precision microbiome management

The future of microbiome armour extends beyond applying individual microbial products. Advances in DNA sequencing and microbial community analysis are helping researchers understand which microorganisms are present in healthy plants and how they interact with pests and pathogens.

In the future scientists may develop crop-specific microbial consortia containing carefully selected bacteria and fungi with complementary functions. Precision agriculture

may also help identify fields where particular microbial treatments are most likely to succeed. AI-assisted analysis could support the selection of microbial combinations by integrating soil properties, crop traits and environmental data. However, these possibilities require further validation. The goal is not simply to introduce more microorganisms into agricultural fields but to establish beneficial communities that perform reliably without disrupting existing ecological relationships.

CONCLUSION

Microbiome armour offers a promising approach to sustainable crop protection by using beneficial microorganisms to strengthen plant defence and suppress selected pests and pathogens. Bacteria such as *Bacillus* and *Pseudomonas* along with fungi such as *Trichoderma*, *Beauveria* and *Metarhizium* provide different protective functions that can complement integrated pest management. The success of this approach depends on selecting the right strain for the right crop and target while ensuring product quality and field effectiveness. With continued research and responsible use beneficial microbes could become important allies in reducing avoidable pesticide use, protecting biodiversity and building healthier agricultural systems.

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