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# Microorganisms as Weed Killing Agents: A Review

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**A B S T R A C T**

Weeds significantly reduce crop yield and quality by competing for nutrients, water, and sunlight. Growing concerns about herbicide resistance and environmental pollution have increased interest in sustainable, non-chemical weed-control methods. Microorganisms such as fungi, bacteria, viruses, protozoa, and actinomycetes offer a natural alternative by suppressing weeds through infection, toxin production, enzyme action, competition, or seed degradation. This review summarizes the major types of weed-killing microorganisms, their mechanisms of action, and the factors influencing their performance, including temperature, humidity, formulation stability, and weed physiology. Although microbial bioherbicides show strong potential, their effectiveness in the field can vary due to environmental challenges and narrow host ranges. Advances in biotechnology, improved formulations, and metabolite-based approaches are helping enhance their reliability. Overall, microorganisms represent a promising eco-friendly tool for integrated weed management and can reduce dependence on chemical herbicides in sustainable agriculture

**Keywords:** Microbial biopesticides, weed management, biological control, bioherbicides, microorganism-based weed control, mode of action, sustainable agriculture, environmental safety, plant pathogens, formulation factors, efficacy determinants, eco-friendly pest control**,** Different Types of Weed

## 1. Introduction

Microorganisms offer a safer, sustainable alternative to chemical herbicides. They work through specific interactions with target weeds. The field's performance is still limited due to formulation and stability studies. Microorganisms such as bacteria, fungi, viruses, and nematodes are widely used as biopesticides because of their ability to naturally suppress insects, weeds, pathogenic microbes, and plants. Unlike conventional chemical pesticides, microbial pesticides act through highly specific biological mechanism such as toxin production, parasitism, competition, or induction of plant defense makes them environmentally safer and less harmful to non-target microorganism. Recent studies emphasize that microbial biopesticides fit well with sustainable agriculture and IPM (integrated pest management) systems due to a decrease in chemical residues, improved soil health, and compatibility with biological diversity. However, challenges remain in achieving constant fields of performance, increasing shelf life, and standardizing regulatory procedures for commercial usage. Updated guidelines from international bodies have also highlighted the importance of quality control and proper formulation to ensure safety and efficacy. Despite their advantages, microbial biopesticides face challenges related to sensitivity to temperature, humidity, and UV exposure, and limited farmer awareness in some regions. Nevertheless, ongoing research and increasing governmental support indicate that microorganisms are poised to play an even larger role in the development of next-generation, sustainable crop protection solutions.

### *1.1 What are weeds?*

Weeds are undesired plants. They are considered as dreadful pests Because the loss produced by them are estimated to be more than those occurring Due to other pests and diseases combined. If they are not controlled, then loss occurs in nutrients, water, light and space increase in cost of labour and equipment, low product quality and problems in marketability, besides enhancing rate of incidence of bacterial, fungal, viral, and insects attack. Some weeds cause allergies.

Ex: Hay fever caused by ragweed, medican tea, yellow dock, and parthenium. Dermatitis is also caused by some of the poisonous weeds.

Fig (1): *Amaranthus viridis*

Fig (2): *Phyllanthus niruri*

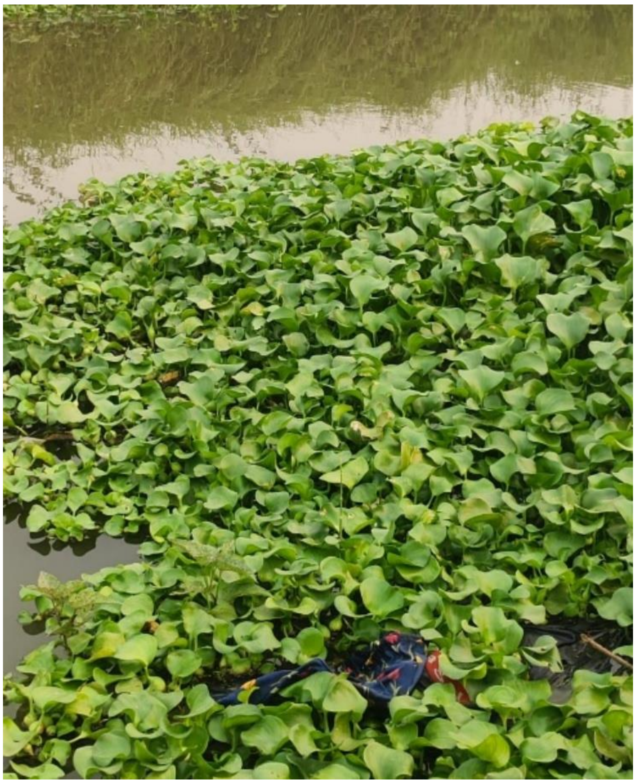

Fig (3) and (4): *Eichhornia crassipes* (Water hyacinth),




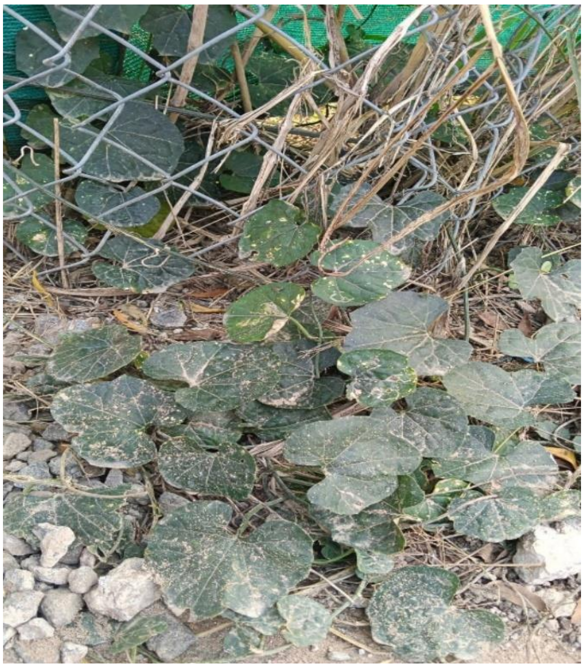

Fig (5),(6),(7),(8),(9),(10),(11),(12): weeds that wiedly grow in feilds

### *1.2 Classification of Weeds*

Weeds are classified into the following types

**A. Classification Based on Life Span**

Weeds are grouped based on how long they survive.

Annuals finish their entire life in one crop season, so they grow fast and produce many seeds. Biennials take two seasons, while perennials persist in fields year after year due to underground storage organs. it is given in table 1, given below

Table 1: Classification Based on Life Span

| **Type of Weed** | **Key Features** | **Common Examples** |
|---|---|---|
| Annual Weeds | Germinate, grow, produce seeds, and complete their life cycle within a single season (usually a few months). They depend only on seeds for regeneration. | *Amaranthus viridis fig(1), Phyllanthus niruri fig(2), Chenopodium album* |
| Biennial Weeds | Grow vegetative structures (roots, stem, leaves) in the first year and produce flowers and seeds in the second year, then die. | *Verbascum thapsus, Daucus carota* |
| Perennial Weeds | Live for multiple years and reproduce through seeds as well as underground organs such as rhizomes, stolons, bulbs and tubers. | *Cyperus rotundus, Cynodon dactylon, Parthenium hysterophorus* |

**B. Classification Based on Plant Type (Morphology)**

- Looking at the structure of the plant helps in identification.
- Grasses and sedges look similar but can be differentiated by stem shape. Broad-leaved weeds are easy to recognise because of their wider leaves and branching habit. Classification is given in detail in Table 2 below

Table 2: Classification Based on Plant Type (Morphology)

| **Type** | **Identification Traits** | **Examples** |
|---|---|---|
| Grasses | Narrow leaf blades, parallel veins, nodes on stems, round and often hollow stems. | *Echinochloa crus-galli, Cynodon dactylon* |

| **Type** | **Identification Traits** | **Examples** |
|---|---|---|
| Sedges | Grass-like weeds with solid, triangular stems and leaves arranged in three rows. | *Cyperus rotundus*, *Cyperus esculentus* |
| Broad-leaved Weeds | Broad lamina, net-veined leaves, branched stems, and prominent taproots. | *Parthenium hysterophorus*, *Amaranthus spp.*, *Tridax procumbens* |

**C. Classification Based on Habitat**

- Different weeds dominate different environments. Aquatic weeds influence water movement,
- while terrestrial weeds compete directly with crops for sunlight and nutrition.

Table 3: Classification Based on Habitat

| **Weed Group** | **Growing Environment** | **Examples** |
|---|---|---|
| Terrestrial Weeds | Thrive in dry or moist soil on agricultural land. | *Parthenium hysterophorus*, *Cynodon dactylon* |
| Aquatic Weeds | Grow either floating or rooted in ponds, canals, and lakes. | *Eichhornia crassipes* (Water hyacinth), *Azolla pinnata* |
| Marshland Weeds | Prefer wet, swampy, and partially waterlogged soils. | *Typha angustifolia*, *Phragmites karka* |

**D. Classification Based on Field Occurrence**

- Where a weed grows is important for management.

  For example, roadside weeds often invade nearby farms and become invasive species.

Table 4: Classification Based on Field Occurrence

| **Category** | **Where They Are Found** | **Examples** |
|---|---|---|
| Crop Field Weeds | Compete with major crops in cultivated land. | *Echinochloa crus-galli*, *Cyperus rotundus* |
| Pasture Weeds | Grow naturally in grazing regions and disturb fodder quality. | *Parthenium hysterophorus*, *Tridax procumbens* |
| Garden or Lawn Weeds | Dominate lawns, parks, playgrounds, and gardens. | *Digitaria sanguinalis*, *Cynodon dactylon* |
| Roadside Weeds | Spread along roads, unused land, and wastelands. | *Lantana camara*, *Ipomoea carnea* |

**E. Classification Based on Origin**

- Native weeds are part of the local environment, but exotic species enter from outside regions and multiply aggressively due to a lack of natural predators.

Table 6: Classification Based on Origin

| **Type** | **Meaning** | **Examples** |
|---|---|---|
| Indigenous/Native Weeds | Species that belong naturally to the local ecosystem. | *Amaranthus viridis*, *Cynodon dactylon* |
| Exotic/Invasive Weeds | Introduced accidentally or intentionally from other regions and spread fast. | *Parthenium hysterophorus*, *Lantana camara*, *Eichhornia crassipes* |

**F. Classification Based on Mode of Reproduction**

- Weeds spread either through seeds or vegetatively.
- Vegetative reproduction makes control difficult because even a small piece of root can grow into a new plant.

Table 6: Classification Based on Mode of Reproduction

| **Reproduction Type** | **How They Multiply** | **Examples** |
|---|---|---|
| Seed-propagated Weeds | Spread mainly through seed formation and dispersal. | *Parthenium hysterophorus*, *Amaranthus viridis* |

| | | |
|---|---|---|
| Vegetatively Spreading Weeds | Reproduce through stolons, tubers, rhizomes, bulbs, or roots. | *Cyperus rotundus*, *Cynodon dactylon* |

**G. Classification Based on Harmful Nature**

- Some weeds are extremely damaging and are labeled as "noxious." They affect soil health, allergen levels, crop yield, and livestock health.

Table 7: Classification Based on Harmful Nature

| **Category** | **Description** | **Examples** |
|---|---|---|
| Noxious Weeds | Causes severe harm to crops, livestock, humans, or environment; difficult to control. | *Parthenium hysterophorus*, *Lantana camara* |
| Non-noxious/Common Weeds | Compete with crops but are relatively easy to manage. | *Amaranthus spp.*, *Chenopodium album* |

***Methods to control weeds***

1. Mechanical methods
2. Agricultural methods
3. Biological methods
4. Chemical methods

Among these methods, using microorganisms as weed-killing agents is a biological method.

"Biological control mainly focuses on keeping harmful weeds at a low level so they don't cause economic loss and environmental damage. The goal isn't to remove every single weed, but to manage them naturally so they stay under control in the long term."

***History of biological methods***

According to a review, "Biological Herbicides: Discovery, Development, Deployment" published in Weed Science (1982), the first two commercial biological herbicides were launched in the early 1980s: namely, DeVine in 1981 (based on the fungus Phytophthora palmivora) and Collego in 1982 (based on Colletotrichum gloeosporioides f. sp. aeschynomene).

A broader historical review outlines that scientific labs began exploring plant-pathogenic fungi as weed control agents in the 1970s, leading to commercial products in the early 1980s. Most recently, research continues for instance; a 2024 paper reports isolation of phytotoxic metabolites from a strain of Colletotrichum gloeosporioides and testing their herbicidal activity — showing that efforts to develop new bioherbicides are ongoing.

## Mode of action in these biological methods

1. Fungal Infection (weeds get natural diseases)

Some fungi specifically target and infect weeds, acting much like plant pathogens that cause disease in their host plants.What happens:

- The fungus lands on the weed's leaves.
- It grows into the plant
- It spreads inside
- The plant becomes sick
- The weed finally dies

**2.** Natural Toxins — "Microbes release plant-killing chemicals"

Certain fungi/bacteria make natural toxic chemicals that are deadly only to weeds.

How it works:

- The microbe sits on the weed
- It releases a toxin
- The toxin bursts the plant's cells
- Leaves turn brown

- Weed collapses

**3.** Enzyme Attack — "Microbes break the weed's body wall"

Microbes produce enzymes (like scissors) that cut through the weed's outer walls.

What happens:

- The enzyme melts/softens the leaf surface
- Microbes get inside easily
- Plant tissues become weak and mushy
- Weed dies due to tissue breakdown

**4.** Water Blockage — "The weed dries from the inside"

Some microbes grow inside the weed's water pipes (xylem).

How it kills the weed:

- Water flow gets blocked
- A plant can't drink water
- It wilts
- It dries up and dies

**5.** Hormone Disturbance — "Microbes confuse the weed's growth signals"

Plants grow using special hormones. Some microbes disturb these hormones. What happens:

- Leaves twist or curl
- Stems swell strangely
- Roots stop growing
- plant becomes weak
- Weed finally dies

**6.** Competition — "Good microbes push weeds aside"

Some beneficial microbes simply occupy space and nutrients before weeds can.

They work by:

- Covering soil or roots
- Consuming nutrients
- Blocking sunlight or growth space
- Preventing weed establishment

**7.** Seed Destruction — "Destroy the weed before it is born"

Some microbes infect weed seeds in the soil.

What they do:

- Rot the seeds
- Prevent germination
- Kill the seedling in the early stage

Classification of biological agents

Different biological agents act as weed killers. They are given below:

1. Viruses
2. Bacteria

3. Fungal
4. Protozoans
5. Actinomycetes
6. Nematodes

## Microorganisms as weed-killing agents: different types of classification

There are different types of microorganisms used as weed-killing agents. They are classified based on different categories as listed below:

1. Based on the type of microorganism
2. Based upon the target pest/disease group
3. Based on the mode of action/formulation.

1. **Based on the type of microorganism**

To understand their role more clearly, these weed-killing microbes are classified based on the type of microorganism they belong to. This classification helps in identifying the type of organism that is useful as a weed killer.

The following is the classification based on the type of microorganism, which is given in Table 8 below

Table 8: Classification based on the type of microorganism

| **Microorganism Type** | **Representative Genera / Species** |
|---|---|
| Bacterial Biopesticides | *Bacillus thuringiensis*, *Bacillus subtilis*, *Pseudomonas fluorescens, Serratia marcescens* |
| Fungal Biopesticides | *Beauveria bassiana*, *Metarhizium anisopliae*, *Trichoderma harzianum*, Verticillium lecanii |
| Viral Biopesticides | Baculoviruses (e.g., NPVs, GVs) |
| Protozoan Biopesticides | *Nosema locustae, Vairimorpha spp.* |
| Actinomycete Biopesticides | *Streptomyces avermitilis, Streptomyces lydicus* |
| Yeast-Based Biopesticides | *Metschnikowia pulcherrima*, *Saccharomyces cerevisiae* (biocontrol strains) |
| Nematophagous Microbial Biopesticides | *Pochonia chlamydosporia, Paecilomyces lilacinus* |

2. **Based upon the target pest/disease group (functional)**

control agents can be grouped according to the specific pests or diseases they target. This type of classification helps us understand which organism is effective against which problem, making biological control more practical and efficient. Instead of using one broad-spectrum chemical for all pests, we use highly specific microorganisms or natural enemies that attack only a certain type of weed, insect, fungus, or pathogen, as given in Table 9 below

Table 9: Classification Based upon the target pest/disease group (functional)

| **Functional Category (Target Type)** | **Microbial Group** | **Representative Microorganisms (Many Examples Included)** |
|---|---|---|
| Bioinsecticides (Targets Insect Pests) | Bacteria | *Bacillus thuringiensis* (Bt), *Bacillus sphaericus, Bacillus popilliae, Pseudomonas entomophila* |
| | Fungi | *Beauveria bassiana, Metarhizium anisopliae, Isaria fumosorosea, Lecanicillium lecanii, Hirsutella thompsonii* |
| | Viruses | Nucleopolyhedroviruses (NPVs), Granuloviruses (GVs), Cypoviruses, Cytoplasmic polyhedrosis viruses |
| | Protozoa | *Nosema locustae, Vairimorpha necatrix, Amoeba proteus* (experimental control) |
| | Actinomycetes | *Streptomyces avermitilis, Streptomyces fradiae* |
| Biofungicides (Targets Fungal Plant Diseases) | Fungi (Antagonistic) | *Trichoderma harzianum, T. viride, T. atroviride, Clonostachys rosea, Gliocladium virens* |

| **Functional Category (Target Type)** | **Microbial Group** | **Representative Microorganisms (Many Examples Included)** |
|---|---|---|
| | Bacteria | *Pseudomonas fluorescens, Bacillus subtilis, Bacillus amyloliquefaciens, Streptomyces lydicus* |
| | Yeasts | *Metschnikowia pulcherrima, Candida oleophila, Aureobasidium pullulans* |
| Bionematicides (Targets Plant-Parasitic Nematodes) | Fungi | *Paecilomyces lilacinus (Purpureocillium lilacinum), Pochonia chlamydosporia, Arthrobotrys oligospora (nematode-trapping)* |
| | Bacteria | *Pasteuria penetrans, Bacillus firmus, Bacillus nematocida, Pseudomonas putida* |
| Bioinsectistats (Reduce Insect Feeding / Reproduction) | Bacteria | *Serratia marcescens, Chromobacterium subtsugae, Burkholderia rinojensis* |
| | Fungi | *Sublethal strains of Beauveria bassiana, Isaria farinosa* |
| | Protozoa | *Nosema pyrausta, Nosema whitei* |
| Bioherbicides (Targets Weeds) | Fungi | *Colletotrichum gloeosporioides f.sp. aeschynomene, Phoma macrostoma, Alternaria cassiae, Fusarium oxysporum f.sp. strigae* |
| | Bacteria | *Xanthomonas campestris* (weed-specific strains), *Pseudomonas fluorescens* D7 |
| Bioacaricides (Targets Mites & Ticks) | Fungi | *Hirsutella thompsonii, Metarhizium anisopliae, Beauveria bassiana* |
| | Actinomycetes | *Streptomyces avermitilis (source of avermectins)* |
| Bioantibacterial Agents (Targets Bacterial Plant Diseases) | Bacteria | *Bacillus subtilis, Bacillus velezensis, Pseudomonas protegens, Streptomyces griseus* |
| | Fungi | *Trichoderma asperellum, Trichoderma koningiopsis* |
| Bioviral Disease Suppressors (Indirect Suppression) | Bacteria | *Bacillus megaterium, Pseudomonas putida, Azotobacter chroococcum* (induce plant resistance) |
| | Fungi | *Trichoderma harzianum, T. virens* |
| Post-Harvest Biocontrol Agents | Yeasts | *Metschnikowia pulcherrima, Candida sake, Rhodotorula glutinis, Debaryomyces hansenii* |
| | Bacteria | *Bacillus amyloliquefaciens, Pantoea agglomerans* |
| Soil-Borne Disease Suppressors | Bacteria | *Bacillus subtilis, Bacillus pumilus, Pseudomonas fluorescens, Streptomyces hygroscopicus* |
| | Fungi | *Trichoderma harzianum, T. viride, Chaetomium globosum* |
| Biostimulant-Microbials (Target: Physiological Stress, Not Pests) | Bacteria | *Azotobacter, Azospirillum, Paenibacillus polymyxa* |
| | Fungi | *Piriformospora indica*, Mycorrhizae species |

3. **Based on the mode of action/formulation**

- Biological control agents can also be classified according to how they act on the target pest or weed. Each organism works differently—some produce toxins, some invade plant tissues, some compete for nutrients, while others trigger natural defense mechanisms in the host plant.
- Classifying biocontrol agents based on their mode of action helps researchers identify which mechanism is most effective for a particular pest problem. It also makes it easier to design targeted, eco-friendly solutions and avoid unnecessary chemical usage. This approach improves efficiency, safety, and sustainability in modern pest and weed management.
- Biological control agents are often classified by the type of formulation in which they are prepared for use. Since microorganisms are living

- entities, they need to be delivered in a form that keeps them stable, viable, and effective.Depending on the purpose, these biocontrol agents
- may be formulated as wettable powders, granules, liquids, capsules, pellets.

Classifying agents by formulation helps determine the best way to store, transport, and apply them in the field. It ensures that microorganisms survive long enough to act on the target pest and provide reliable, consistent control. This method improves the practicality and commercial usability of biological weed and pest control products. The classification is given in table 10 below

Table 10; classification is based on Based on the mode of action/formulation based

| **Mode of Action / Delivery / Formulation Approach** | **Explanation (How It Works / What It Does)** | **Representative Microbes or Formulation Types / Notes** |
|---|---|---|
| Direct infection/parasitism by living microbes | Microbe (fungus, virus, nematode, or pathogenic bacterium) infects the target pest or pathogen — penetrates the cuticle or body wall (in insects, nematodes), multiplies inside, leads to death or suppression. | ➢ Entomopathogenic fungi — e.g. Beauveria bassiana, Metarhizium anisopliae<br>➢ Entomopathogenic nematodes (or microbial-nematode biocontrol) Viral agents — baculoviruses / nucleopolyhedroviruses (for insect larvae) |
| Antibiosis/toxin- or metabolite-based action | Microorganisms secrete toxins, enzymes, antibiotics or bioactive metabolites that kill or inhibit pests/pathogens (insect larvae, fungal pathogens, bacteria), without requiring physical infection. | ➢ Bacterial biopesticides: e.g. Bacillus thuringiensis (Bt) — produces insecticidal proteins, toxins; other bacteria producing lipopeptides, antifungal or antibacterial metabolites.<br>➢ Some fungi or actinomycetes that secrete antifungal or insecticidal compounds. Use of microbial-derived metabolites (rather than live microbes) as active ingredients. |
| Competition/niche exclusion/colonization/resource competition | Beneficial microbes colonize plant surfaces (leaf, root, soil, rhizosphere) or wounds, occupy physical or nutritional niches — outcompeting pathogens/pests for space or nutrients, or altering the micro-environment to inhibit pathogen/pest establishment. | ➢ Soil- or rhizosphere-inhabiting bacteria (e.g. Bacillus, Pseudomonas) that colonize roots and suppress soil pathogens.<br>➢ Antagonistic fungi such as Trichoderma spp. that colonies the root or soil and compete with pathogenic fungi.<br>➢ Yeasts or bacterial colonizers used as bio-protective agents (on fruit surfaces, seeds, soil) to prevent pathogen establishment. |
| Induced systemic resistance / plant-immune stimulation / growth-promotion + protection | Microbes or their metabolites, when applied (soil drench, root inoculation, seed treatment, foliar spray), stimulate the plant's own defense mechanisms — making plants more resistant to pests/pathogens; may also promote growth and resilience. | ➢ Beneficial rhizobacteria or fungi (e.g. Bacillus, Trichoderma) used as biocontrol + growth-promoting agents.<br>➢ Microbial formulations that combine pesticidal effect + plant health enhancement (biopesticide plus biofertilizer effect). |
| Formulated microbial-derived compounds (non-living) — metabolite-based or natural-compound biopesticides | Instead of applying live microbes, purified or semi-purified toxins, enzymes or metabolites (from microbes or other biological sources) are formulated and applied — useful when storage, shelf-life, or field viability of living microbes is problematic. | ➢ Biopesticides based on microbial metabolites or natural products (e.g. secondary metabolites, enzymes) formulated as powders, liquids, or concentrates. |

| **Mode of Action / Delivery / Formulation Approach** | **Explanation (How It Works / What It Does)** | **Representative Microbes or Formulation Types / Notes** |
|---|---|---|
| | | ➢ Biopesticide formulations derived from biomass or extracts of microbes rather than live cells. |
| Nano- or microencapsulation / nanotechnology-based formulations for improved stability & controlled release | Active agents (microbial spores/cells or microbial-derived compounds) are encapsulated in nano-/micro-scale carriers (polymers, nanogels, nanoparticles) to protect them from environmental stress (UV, desiccation, heat), improve shelf-life, and enable slow or controlled release — enhancing field efficacy. | ➢ Nano-formulated biopesticides: using nanocarriers, nanogels, polymer coatings, nano-capsules to encapsulate microbial spores or metabolites.<br>➢ Advanced formulations such as polymer-coated granules or tablets, hydrogels, nano-emulsions, for controlled/delayed release. |
| Controlled-release formulations / soil-delivery granules / seed coatings / soil-drench / moisture-activated release systems | Biopesticide (microbe or metabolite) is formulated into granules, pellets, coated seeds or soil-applied matrices that remain dormant until triggered by soil moisture or environmental conditions — releasing agents gradually over time for sustained activity. | ➢ Soil granules containing fungal spores or microbial agents for soil-dwelling pests / pathogens.<br>➢ Seed coatings with microbial biocontrol agents to protect seedlings from soil<br>pathogens / early-stage pests.<br>Moisture-responsive hydrogels, polymer granules releasing microbes upon watering / rainfall. |
| Liquid / spray / foliar / emulsion / suspension formulations (traditional application methods) | Microbial spores, cells or microbial-derived compounds are formulated as spray suspensions, emulsions, or wettable powders, then applied via foliar spray or seed/soil treatment — widely used method for above-ground pests or pathogens. | ➢ Wettable powders, liquid suspensions or emulsions of fungal spores (e.g. conidia of Beauveria, Metarhizium) or bacterial cells.<br>➢ Emulsion / oil-based formulations to improve adhesion, spread, or persistence on plant surfaces. |

***Factors Affecting How Well Microorganisms Kill Weeds***

➢ The success of microorganisms as weed killers depends on many real-world conditions. Since these agents are living organisms, they work best only when the environment supports their growth and activity. Factors like temperature, humidity, rainfall, and soil conditions play a major role. For example, some fungi need moisture or dew on the leaves to infect weeds, and if the weather is too dry or too hot, they simply won’t work as expected.

➢ The formulation of the biocontrol product is also very important. The microbes must stay alive during storage and after application. If the formulation is weak or poorly prepared, the microorganisms may die before they even reach the weed. The way the product is applied—such as the amount of water used, spray quality, and timing—also decides how well it will work in the field.

➢ Different weeds respond differently. Some have thick leaf surfaces or protective layers that make it harder for microbes to infect them. Many microbial weed killers only target specific weed types, so choosing the right agent for the right weed is essential.

➢ Microbes that kill weeds by producing toxins must be healthy enough to make those chemicals. If they are stressed or exposed to harsh conditions, they may not produce enough toxins to affect the weed.

➢ Finally, farming practices—such as irrigation, fertilizer use, and soil management—can either help or hinder microbial performance. Other microbes in the environment may also compete with, support, or suppress the weed-killing microorganism.

➢ Overall, microbial weed control is effective, but it works best when the environment, formulation, application, and crop practices all align to support the microorganism.

## Key Factors Influencing Efficacy of Microbial Weed-Killing Agents

1. Environmental conditions (weather, moisture, temperature, humidity, light, soil, etc.)
2. Formulation and viability of the microbial agent
3. Application method and technique
4. Host weed species (and weed characteristics)
5. Bioactive compound content / Microbial metabolic activity
6. Integration with agricultural practices & ecosystem interactions

1. **Environmental conditions (weather, moisture, temperature, humidity, light, soil, etc.)**

- Many bioherbicide formulations, especially fungal ones, require certain conditions (like leaf wetness / dew, high humidity, moderate temperature) for the fungus to infect weed leaves, sporulate, and successfully cause disease.
- For example, one study showed that some fungal isolates need dew or free moisture (leaf wetness) for a certain duration — without that, infection fails, and bioherbicide doesn't work. Soil conditions (moisture, soil type), ambient temperature, humidity, and even light/UV can affect microbial survival and effectiveness.
- Because environmental conditions vary in real fields (vs. controlled lab), efficacy seen in lab/greenhouse often drops in actual field use.

2. **Formulation and viability of the microbial agent**

- Since bioherbicides are living (or once-living) organisms, their viability matters — they must survive storage, transport, and field conditions to be effective.
- Formulation type — e.g. dried spores, wettable powders, liquids — impacts how well microorganisms survive and perform.
- If formulation isn't optimized (wrong carrier, poor storage, improper application), microbes may die or fail to produce toxins/spores, reducing weed-killing activity.

3. **Application method and technique**

- How the bioherbicide is applied — spray droplet size, distribution, volume of water, method of delivery — impacts coverage and contact with weed tissues.
- The quality of spray water (pH, hardness, impurities) can affect microbial survival or activity — poor water quality may reduce effectiveness.
- Timing of application relative to weed growth stage, weed physiology, and environmental conditions (before/after rain, humidity, dew) influences success.

4. **Host weed species (and weed characteristics)**

- Bioherbicides often have narrow host range — meaning a microbial agent may work well only on certain weed species, not all.
- Weed morphological characteristics — leaf surface (cuticle, wax, hairs), root vs. shoot, seed vs. mature weed, etc. — affect whether microbes can infect, adhere, or produce toxins successfully

5. **Bioactive compound content / Microbial metabolic activity**

- For microbial bioherbicides that kill via toxins or phytotoxic metabolites (rather than infection), the amount and potency of those metabolites is crucial for efficacy.
- Microbial physiological status matters: if microbes are stressed (due to improper formulation, storage, environment), they may not produce enough toxins or may die before acting.

6. **Integration with agricultural practices & ecosystem interactions**

- Farming practices — tillage, irrigation, fertilisation — influence soil and micro-climate conditions, which in turn influence microbial survival and efficacy.
- Microbial bioherbicides may interact with other microbes, soil micro-flora, non-target organisms — these interactions can boost or hinder efficacy depending on competition, antagonism, or synergy.

***What research says about the limits of microbe-based weed control***

- Limited efficacy and narrow target range

- Environmental dependence and variability
- Technical, production and economic constraints
- Biological/ecological challenges and predictability issues
- Integration and compatibility problems with conventional practices

**Limited efficacy and narrow target range**

- Many microbial bioherbicides show low or inconsistent weed-control performance in field conditions — although they may work under controlled lab conditions; they often fail to suppress weeds effectively in real farming environments.
- Microbial agents often have high "host specificity", meaning they may suppress only certain weed species and fail on others.
- Because of this specificity and limited weed-spectrum, one single microbial agent rarely works as a "broad-spectrum" herbicide.

**Environmental dependence and variability**

- The success of microbial weed control depends strongly on environmental conditions (soil type, climate, moisture, temperature, etc.). Adverse or suboptimal conditions may reduce microbial activity or survival, lowering weed-control efficacy
- Microbial bioherbicides often have short persistence in the environment (short environmental half-life), which reduces the duration of weed-suppression — weeds may regrow once the microbial agent declines.

**Technical, production and economic constraints**

- Mass production and formulation of microbial agents is difficult: many promising microbes fail to scale up to commercial production because of inoculum-production challenges, storage/shelf-life issues, and cost.
- The small, specialized target markets and fragmented demand for bioherbicides mean low commercial interest and investment — limiting research, development, and widespread adoption.
- There are regulatory, safety, and standardization considerations: live microbial agents (especially pathogens) may raise biosafety concerns, and ensuring consistent potency and safety across batches is challenging.

**Biological/ecological challenges and predictability issues**

- For weed-seed bank suppression: although some microbes can degrade weed seeds or reduce their viability, research is limited; there is no guarantee that all "persistent" seeds in soil will be eliminated by microbes
- Microbial suppression can be slow and gradual, not instantaneous like chemical herbicides — so in the short-term weeds may still compete with crops.
- Because many bioherbicides don't completely kill weeds but only reduce their growth or competitiveness (e.g. reducing biomass or seed production), repeated or integrated management (with other weed-control methods) is usually necessary.

**Integration and compatibility problems with conventional practices**

- When microbial methods are combined with chemical herbicides or other agro-inputs, incompatibility issues may arise. Chemical herbicides can harm beneficial or weed-suppressing microbes, reduce soil-microbe diversity, or inhibit microbial bioherbicide efficacy.
- In many cropping systems, using only biological control may not be enough — integration with mechanical, cultural, or chemical methods may still be required. This reduces the "standalone" attractiveness of microbial weed control.

## Future Aspects of Using Microorganisms in Weed-Killing Processes

- The use of microorganisms for weed control is expected to grow rapidly in the future as agriculture moves toward safer, greener, and more sustainable practices. Chemical herbicides have been heavily relied on for decades, but increasing problems like herbicide resistance, environmental pollution, and health concerns are pushing farmers and researchers to look for better alternatives. Microbial weed killers offer a natural, eco-friendly solution—and their future looks promising.
- In the coming years, advances in genomics, biotechnology, and microbial engineering will help scientists discover new microorganisms with stronger weed-killing abilities. We will be able to identify the exact genes and metabolites responsible for suppressing weeds, allowing the development of more targeted, efficient bioherbicides.
- Future formulations will also become more stable, easier to store, and more effective in real field conditions. Modern encapsulation technologies, protective carriers, and improved spray systems will help microorganisms survive harsh sunlight, dry weather, and long transport. This will finally solve the biggest challenge of bioherbicides—their inconsistency under field conditions.

- We may also see smart bioherbicides that activate only in the presence of specific weeds, reducing harm to crops and beneficial organisms. Microbial consortia—combinations of multiple microbes working together—will provide stronger, multi-mechanism of weed suppression.
- As consumers demand chemical-free food and governments push for reduced pesticide use, microbial weed control will become a key part of sustainable and organic farming. With rising interest in climate-resilient agriculture, these natural weed-killing agents will support soil health, biodiversity, and long-term productivity.
- Overall, the future of microbial weed killers is bright, with huge potential for innovation, safer agriculture, and eco-friendly weed management.

**1. Discovery of New Microbial Weed Killers**

Future research will focus on identifying new microorganisms with stronger, more specific weed-killing abilities. With advanced DNA sequencing and microbiome studies, scientists will be able to explore soil, plant surfaces, and extreme environments to find unique microbes that can target troublesome weeds effectively.

**2. Genetic and Biotechnological Improvements**

Biotechnology will allow scientists to understand the exact genes and pathways that help microorganisms suppress weeds. This knowledge will support the development of more powerful strains, engineered microbes, and enhanced metabolites that selectively attack weeds without harming crops or the environment.

**3. Improved and Stable Formulations**

One major barrier today is that microbes often struggle to survive sunlight, heat, dryness, and storage conditions. In the future, improved formulations such as microencapsulation, biofilms, granules, wettable powders, and oil-based carriers will protect microorganisms and keep them effective for longer periods, even under harsh field conditions.

**4. Smart, Target-Specific Bioherbicides**

Future microbial products may become “smart”, meaning they activate only when they detect specific weed species or environmental signals. This will give extremely precise weed control and reduce any chance of affecting crops or beneficial organisms. Such precision will help replace broad-spectrum chemical herbicides.

**5. Use of Microbial Consortia**

Instead of using a single microorganism, future weed management may use microbial consortia—carefully selected combinations of fungi, bacteria, and other microbes that work together. These groups can attack weeds using multiple mechanisms at once, making control more reliable and reducing the chance of weed resistance.

**6. Integration Into Sustainable and Organic Farming**

As farmers and consumers demand chemical-free food, microbial weed killers will become a core part of integrated weed management. They support soil health, protect biodiversity, and reduce chemical residues. Their adoption will grow especially in organic farming, climate-resilient agriculture, and eco-friendly production systems.

**7. Reduced Herbicide Resistance Problems**

Chemical herbicides are facing massive issues with resistant weeds. Microbial agents work differently and can attack weeds through infection, toxin production, or competition. In the future, these biological tools will help manage or delay herbicide resistance, offering a long-term solution for weed control.

**8. Government Support and Commercial Expansion**

Governments worldwide are promoting reduced chemical pesticide use. Funding, training, and regulatory support will encourage the development of microbial bioherbicide industries. This will lead to easier availability, lower cost, and adoption at the farmer level.

## Literature review on usage of microorganisms as weed killing agents:

Table 11: Literature review recent 5 years

| Referenced (Authors, Year) | What It Supports / Key Ideas from Your Future Outlook |
|---|---|
| Achievements, Developments and Future Challenges in the Field of Bioherbicides for Weed Control (2022) | Shows the promise of bioherbicides as eco-friendly alternatives to synthetic herbicides; discusses the need for discovering new microbial sources, scaling up production, and research into environmental influences on efficacy (e.g. $CO_2$, humidity, UV, soil stress). |

| **Referenced (Authors, Year)** | **What It Supports / Key Ideas from Your Future Outlook** |
|---|---|
| Bioherbicides: An Eco-Friendly Tool for Sustainable Weed Management (2023) | Reviews how bioherbicides (microbe-based or plant-extract based) can suppress weeds, reduce reliance on chemicals, and fit into sustainable agriculture — supporting the shift toward greener farming practices. |
| The future of microbial bioherbicides (2024) | Directly addresses the future — outlines the challenges limiting current microbial herbicides (formulation, stability, host-range), and points to future opportunities: improved application technology, genetic/biotech enhancements, formulation improvements, and broader adoption. |
| Agroecological Weed Management and the Potential Role of Fungi-Based Bioherbicides in Conservation: Advantages, Applications and Future Prospects (2024) | Emphasizes integrating fungal bioherbicides into sustainable/ agroecological weed management, noting that use of bioherbicides should be complementary to other practices — aligning with the idea of integrated and sustainable farming. |
| Allelopathy as a source of bioherbicides: challenges and prospects for sustainable agriculture (2023) | Offers a look at plant-derived bioherbicides (allelochemicals) and the growing interest in them as part of sustainable weed management — showing broader biological-control strategies beyond just microbes. |

## Conclusion:

Microorganisms have emerged as highly promising agents for sustainable weed management, offering a natural and environmentally safe alternative to chemical herbicides. Their diverse mechanisms—such as pathogenic infection, production of phytotoxic metabolites, competition for nutrients, interference with plant hormones, and seed degradation—enable them to target weeds with remarkable specificity while preserving beneficial organisms and improving soil health. Although field performance is sometimes limited by environmental factors, formulation challenges, and narrow host range, ongoing advancements in biotechnology, microbial isolation, nanoencapsulation, and metabolite-based herbicides are steadily overcoming these barriers. The growing global demand for chemical-free agriculture, along with rising herbicide resistance, makes microbial weed control increasingly relevant for future farming systems. Research continues to identify more efficient microbial strains, develop stable formulations, and integrate these agents into broader weed-management frameworks. As governments, farmers, and scientists move toward sustainable and climate-resilient agriculture, microbial bioherbicides are positioned to play a central role in reducing chemical inputs and ensuring long-term ecological balance. Overall, microorganisms represent a powerful, safe, and scalable tool that holds significant potential to revolutionize modern weed-control practices.

**References:**

1. Raza T, Qadir MF, Imran S, Khatoon Z, Khan MY, Mechri M, Asghar W, Rehmani MIA, Villalobos SLS, Mumtaz T, Iqbal R. Bioherbicides: revolutionizing weed management for sustainable agriculture in the era of One-health. Curr Res Microb Sci. 2025 Apr 17; 8:100394. Doi: 10.1016/j.crmicr.2025.100394. PMID: 40391281; PMCID: PMC12088770.

2. Wend K, Zorrilla L, Freimoser FM, Gallet A. Microbial pesticides - challenges and future perspectives for testing and safety assessment with respect to human health. Environ Health. 2024 May 29;23(1):49. Doi: 10.1186/s12940-024-01090-2. PMID: 38811948; PMCID: PMC11134743. https://doi.org/10.4060/cb8401en

3. Li K, Chen M, Shi J, Mao T. An overview of the production and use of Bacillus thuringiensis toxin. Open Life Sci. 2024 Aug 6;19(1):20220902. Doi: 10.1515/biol-2022-0902. PMID: 39119481; PMCID: PMC11306962.

4. Chakraborty N, Mitra R, Pal S, Ganguly R, Acharya K, Minkina T, Sarkar A, Keswani C. Biopesticide Consumption in India: Insights into the Current Trends. Agriculture. 2023; 13(3):557. https://doi.org/10.3390/agriculture13030557

5. Tadesse Mawcha K, Malinga L, Muir D, Ge J, Ndolo D. Recent Advances in Biopesticide Research and Development with a Focus on Microbials. F1000Res. 2025 Mar 11;13:1071. Doi: 10.12688/f1000research.154392.5. PMID: 39512238; PMCID: PMC11541078.

6. Fenibo Emmanuel O., Ijoma Grace N., Matambo Tonderayi, Biopesticides in Sustainable Agriculture: A Critical Sustainable Development Driver Governed by Green Chemistry Principles, Frontiers in Sustainable Food Systems, Volume 5 – 2021, 2021https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2021.619058, DOI=10.3389/fsufs.2021.619058, ISSN=2571-581X

7. Dhatwalia N. Mating behaviour of Cavariella aegopodii. Himalayan Journal of Agriculture. 2024 Jan;5(1):1-7.

8. Ayesha Areej, Muhammad Usama, Umer Zulfiqar, Fatima Sarwar, Maryam, Aneela Ashiq (2024). "Biopesticides in Sustainable Agriculture: Enhancing Targeted Pest Control and Ecosystem Health", Applied Agriculture Sciences, 2(1),1-8,10006.

9. Karaoğlan, B., Alkassab, A.T., Borges, S. et al. Microbial pesticides: challenges and future perspectives for non-target organism testing. Environ Sci Eur 36, 205 (2024). https://doi.org/10.1186/s12302-024-01017-1

10. Haoni Luan, Yue Zhang, Wenhan Qiu, Xue Zhang, Mengyu Liu, Wei Feng, Wei Xu, Fei Wang, Hongzhuan Xuan, Peng Song,Research progress on microbial pesticides,Pesticide Biochemistry and Physiology,Volume 213,2025, 106512, ISSN 0048-3575(https://www.sciencedirect.com/science/article/pii/S0048357525002251) https://doi.org/10.1016/j.pestbp.2025.106512

11. 11.Ritu mawar,Microbial formulations: an alternative for chemical pesticides,asian-pacific biofertilizers and biopesticides information platform,2024, Doi: https://doi.org/10.56669/VNFT9299

12. Trinh Thi Xuan, Comparison of the effectiveness of freeze and spray-dried Bacillus thuringiensis preparations as a biopesticide for the control of cucumber moth, Diaphania indica (Pyralidae: Lepidoptera), International Journal of Environmental Sciences ISSN: 2229-7359 Vol. 11 No. 4S, 2025, https://theaspd.com/index.php/ijes/article/download/637/470

13. Biopesticides industry research report 2024-2030 | lucrative opportunities emerge as microbial biopesticides dominate but biochemical variants rising fast - researchandmarkets.com https://www.businesswire.com/news/home/20250827641778/en/Biopesticides-Industry-Research-Report-2024-2030-Lucrative-Opportunities-Emerge-as-Microbial-Biopesticides-Dominate-but-Biochemical-Variants-Rising-Fast---ResearchAndMarkets.com.

14. "Biopesticides Industry Research Report 2025 | Global Market" https://www.globenewswire.com/news-release/2025/08/25/3138254/0/en/Biopesticides-Industry-Research-Report-2025-Global-Market-to-Reach-14-7-Billion-by-2030-As-Demand-Rises-for-Organic-Residue-free-Produce-and-Growing-Environmental-Awareness-and-Reg.html.

15. Shivli Singh, Bolagam Ravikumar, Kulbir Singh. Biotechnology and technological advancements in agriculture: A review. Int J Res Agron 2025;8(5):328-338. DOI: 10.33545/2618060X.2025.v8.i5e.2906

16. Verma, M.L.; Kumar, A.; Chintagunta, A.D.; Samudrala, P.J.K.; Bardin, M.; Lichtfouse, E. Microbial Production of Biopesticides for Sustainable Agriculture. Sustainability 2024, 16, 7496. https://doi.org/10.3390/su16177496

17. Maxwell Wilson, Next-Generation Biopesticides: Shaping the Future of Crop Protection, Advances in Crop Science and A Technology, 2024, 12:10 https://www.omicsonline.org/open-access-pdfs/nextgeneration-biopesticides-shaping-the-future-of-crop-protection.pdf

18. Raja reddy gundreddy ,et.al, Recent Advances in Biopesticide Formulations for Targeted Insect Pest Management: A Review, Journal of Experimental Agriculture International,2024, volume 46 https://doi.org/10.9734/jeai/2024/v46i92885

19. Haoni Luan, Yue Zhang, Wenhan Qiu, Xue Zhang, Mengyu Liu, Wei Feng, Wei Xu, Fei Wang, Hongzhuan Xuan, Peng Song,Research progress on microbial pesticides,Pesticide Biochemistry and Physiology,Volume 213,2025,106512, ISSN 0048-3575,https://doi.org/10.1016/j.pestbp.2025.106512.(https://www.sciencedirect.com/science/article/pii/S0048357525002251)

20. Shivli Singh, Bolagam Ravikumar, Kulbir Singh. Biotechnology and technological advancements in agriculture: A review. Int J Res Agron 2025;8(5):328-338. DOI: 10.33545/2618060X.2025.v8.i5e.2906

21. Verma ML, Kumar A, Chintagunta AD, Samudrala PJK, Bardin M, Lichtfouse E. Microbial Production of Biopesticides for Sustainable Agriculture. Sustainability. 2024; 16(17):7496. https://doi.org/10.3390/su16177496

22. A textbook of pharmacognosy, C.K. Kokate,A.P. purohit,S.B. ghokale,56th edition,nirali prakashan publishers.

23. Templeton GE. Biological Herbicides: Discovery, Development, Deployment. Weed Science. 1982;30(4):430-433. Doi:10.1017/S0043174500040893

24. A textbook of Biological Control of Weeds: Theory and Practical Application, Mic Julien and Graham White.

25. Xu, Z.; Shi, M.; Tian, Y.; Zhao, P.; Niu, Y.; Liao, M. Dirhamnolipid Produced by the Pathogenic Fungus Colletotrichum gloeosporioides BWH-1 and Its Herbicidal Activity. Molecules 2019, 24, 2969. https://doi.org/10.3390/molecules24162969

26. Ocán-Torres, D., Martínez-Burgos, W. J., Manzoki, M. C., Soccol, V. T., Neto, C. J. D., & Soccol, C. R. (2024). Microbial Bioherbicides Based on Cell-Free Phytotoxic Metabolites: Analysis and Perspectives on Their Application in Weed Control as an Innovative Sustainable Solution. Plants, 13(14), 1996. https://doi.org/10.3390/plants13141996.

27. Roberts, J., Florentine, S., Fernando, W. G. D., & Tennakoon, K. U. (2022). Achievements, Developments and Future Challenges in the Field of Bioherbicides for Weed Control: A Global Review. Plants, 11(17), 2242.https://doi.org/10.3390/plants11172242

28. Hasan, M., Ahmad-Hamdani, M. S., Rosli, A. M., & Hamdan, H. (2021). Bioherbicides: An Eco-Friendly Tool for Sustainable Weed Management. Plants, 10(6), 1212. https://doi.org/10.3390/plants10061212

29. Duke SO, Marrone PG, Vurro M. The future of microbial bioherbicides. Pest Manag Sci. 2024 Jan;80(1):6-7. doi: 10.1002/ps.7885. PMID: 38091278.

30. 30.Petraki, D., Kanatas, P., Zannopoulos, S., Kokkini, M., Antonopoulos, N., Gazoulis, I., & Travlos, I. (2024). Agroecological Weed Management and the Potential Role of Fungi-Based Bioherbicides in Conservation: Advantages, Applications and Future Prospects. Conservation, 4(4), 847-859. https://doi.org/10.3390/conservation4040050
31. Kostina-Bednarz, M., Płonka, J. & Barchanska, H. Allelopathy as a source of bioherbicides: challenges and prospects for sustainable agriculture. Rev Environ Sci Biotechnol 22, 471–504 (2023). https://doi.org/10.1007/s11157-023-09656-1
32. Weed Management in Transition, Volume 2, Edited by Jerry A. Ivany Agriculture and Agri-Food Canada, Crops and Livestock Research Centre. Charlottetown, Prince Edward Island, Canada.
33. Roberts, J., Florentine, S., Fernando, W. G. D., & Tennakoon, K. U. (2022). Achievements, Developments and Future Challenges in the Field of Bioherbicides for Weed Control: A Global Review. Plants, 11(17), 2242. https://doi.org/10.3390/plants11172242
34. 34.Efficacy Improvement of a Bioherbicidal Fungus Using a Formulation-Based Approach" written by Clyde D. Boyette, Robert E. Hoagland, Kenneth C. Stetina, published by American Journal of Plant Sciences, Vol.7 No.16, 2016
35. Duke SO. Why are there no widely successful microbial bioherbicides for weed management in crops? Pest Manag Sci. 2024 Jan;80(1):56-64. doi: 10.1002/ps.7595. Epub 2023 Jun 15. PMID: 37271934.
36. Islam AKMM, Karim SMR, Kheya SA, Yeasmin S. Unlocking the potential of bioherbicides for sustainable and environment friendly weed management. Heliyon. 2024 Aug 10;10(16):e36088.doi: 10.1016/j.heliyon. 2024.e36088. Erratum in: Heliyon. 2025 May 07;11(10):e43383. doi: 10.1016/j.heliyon. 2025.e43383. PMID: 39224292; PMCID: PMC11366919.
37. A.c.kennedy, Microorganisms in Weed Control Strategies,1996,journal of production agriculture, https://doi.org/10.2134/jpa1996.0480
38. Gao, W.-T., & Su, W.-H. (2024). Weed Management Methods for Herbaceous Field Crops: A Review. Agronomy, 14(3), 486. https://doi.org/10.3390/agronomy14030486
39. Sawicka, B., Barbaś, P., Vambol, V., Skiba, D., Pszczółkowski, P., Niazi, P., & Bienia, B. (2025). Applied Microbiology for Sustainable Agricultural Development. Preprints. https://doi.org/10.20944/preprints202506.2374.v1
40. Kremer RJ. Management of Weed Seed Banks with Microorganisms. Ecol Appl. 1993 Feb;3(1):42-52.doi: 10.2307/1941791. PMID: 27759226.
41. Petraki, D., Kanatas, P., Zannopoulos, S., Kokkini, M., Antonopoulos, N., Gazoulis, I., & Travlos, I. (2024). Agroecological Weed Management and the Potential Role of Fungi-Based Bioherbicides in Conservation: Advantages, Applications and Future Prospects. Conservation, 4(4), 847-859. https://doi.org/10.3390/conservation4040050
42. Tayna Sousa Duque, Rodrigo Almeida Pinheiro, Iasmim Marcella Souza, Gabriele Gonçalves Silva, Marcus Alvarenga Soares, José Barbosa dos Santos,Herbicides and bio-inputs: Compatibility and challenges for sustainable agriculture,Chemosphere,Volume 369,2024,143878,ISSN 0045-6535,https://doi.org/10.1016/j.chemosphere.2024.143878,(https://www.sciencedirect.com/science/article/pii/S0045653524027851)
43. Kennedy, A. C., & Kremer, R. J. (1996b). Microorganisms in weed control strategies. Jpa, 9(4), 480–485. https://doi.org/10.2134/jpa1996.0480
44. Petraki, D., Kanatas, P., Zannopoulos, S., Kokkini, M., Antonopoulos, N., Gazoulis, I., & Travlos, I. (2024). Agroecological weed management and the potential role of Fungi-Based bioherbicides in conservation: Advantages, applications and future prospects. Conservation, 4(4), 847–859. https://doi.org/10.3390/conservation4040050
45. Kennedy, A. C., & Kremer, R. J. (1996). Microorganisms in Weed Control Strategies. Journal of Production Agriculture, 9(4), 480–485. https://doi.org/10.2134/jpa1996.0480
46. Petraki, D., Travlos, I., Gazoulis, I., Antonopoulos, N., Kanatas, P., Kokkini, M., & Zannopoulos, S. (2024). Agroecological Weed Management and the Potential Role of Fungi-Based Bioherbicides in Conservation: Advantages, Applications and Future Prospects. Conservation, 4(4), 847–859. https://doi.org/10.3390/conservation4040050
47. Gupta, N., Roy, B., Shanmugaiah, V., & Nighojkar, A. (2024). Phoma herbarum: A Potential Biocontrol Agent Against Weeds, that Promotes Wheat Growth. Current Agriculture Research Journal, 12(2), 773–785. https://doi.org/10.12944/carj.12.2.22
48. Sawicka, B., Barbaś, P., Vambol, V., Skiba, D., Pszczółkowski, P., Niazi, P., & Bienia, B. (2025). Applied Microbiology for Sustainable Agricultural Development. Preprints. https://doi.org/10.20944/preprints202506.2374.v1
49. Islam AKMM, Karim SMR, Kheya SA, Yeasmin S. Unlocking the potential of bioherbicides for sustainable and environment friendly weed management. Heliyon. 2024 Aug 10;10(16):e36088. doi: 10.1016/j.heliyon.2024.e36088. Erratum in: Heliyon. 2025 May 07;11(10):e43383. doi: 10.1016/j.heliyon.2025.e43383. PMID: 39224292; PMCID: PMC11366919.
50. Boyette, C. D., Hoagland, R. E., & Stetina, K. C. (2016). Efficacy Improvement of a bioherbicidal fungus using a Formulation-Based approach. American Journal of Plant Sciences, 07(16), 2349–2358. https://doi.org/10.4236/ajps.2016.716206

51. Gupta, A. K., & Yadav, D. (2020). BIOLOGICAL CONTROL OF WATER HYACINTH. Environmental Contaminants Reviews, 3(1), 37–39. https://doi.org/10.26480/ecr.01.2020.37.39