

## **New Generation Biopesticides: A Sustainable Tool for Environmental Protection**

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### **Abstract**

The increasing environmental and health concerns associated with synthetic pesticides have accelerated the search for safer alternatives. New generation biopesticides, derived from natural sources such as microorganisms, plants and semiochemicals, offer an eco-friendly and target-specific approach to pest management. These biopesticides not only reduce chemical residues in food and soil but also help in conserving biodiversity and maintaining ecological balance. Recent advancements in biotechnology, nanotechnology and formulation science have significantly enhanced their efficacy, shelf life and field applicability. This article discusses the types, mechanisms, advantages, challenges and future prospects of new generation biopesticides in ensuring sustainable agriculture and environmental protection.

### **Introduction**

The green revolution's technology has led to significant increases in agricultural productivity through high-yielding varieties, chemical fertilizers and pesticides. However, this input-intensive approach has negatively impacted the environment and the sustainability of farming systems. The use of synthetic pesticides has harmed both abiotic and biotic factors, resulting in pesticide residues in soil, air and water and causing detrimental effects like physiological deformities, diseases and genetic disorders in various organisms. Chemicals like DDT, used broadly to control pests, have contaminated food and water sources, harmed beneficial insects and fostered resistance in pest populations.

Agriculture has long relied on chemical pesticides to ensure crop productivity and food security. However, indiscriminate use of synthetic pesticides has led to serious consequences such as environmental pollution, pest resistance, resurgence and adverse effects on non-target organisms, including humans (Pimentel, 2005). These concerns have prompted a paradigm shift toward sustainable pest management strategies.

Biopesticides have emerged as a viable alternative due to their eco-friendly nature, specificity and compatibility with integrated pest management (IPM) systems. The new generation biopesticides go beyond traditional formulations and include advanced microbial strains, genetically improved bioagents, RNA

interference (RNAi)-based products and nano-formulations (Kumar *et al.*, 2020). These innovations are transforming pest management practices and contributing to environmental sustainability.

### What is Biopesticide?

Biopesticides, which are created from naturally occurring compounds and manage pests through non-toxic and environmentally benign methods, are becoming more and more popular worldwide. Animals (such as nematodes), plants (such as Chrysanthemum, Azadirachta) and microorganisms (such as *Bacillus thuringiensis*, *Trichoderma* and nucleopolyhedrosis virus) can all be the source of biopesticides, which include living organisms (natural enemies), their products (phytochemicals, microbial products) or byproducts (semiochemicals) that can be used to control harmful pests (Majid *et al.* 2011). The tried-and-true indigenous technical knowledge (ITK) of controlling pests using natural materials has proven to be highly successful, but many ITKs have been forgotten as a result of the introduction and use of chemical pesticides. The environment and human health are less threatened by biopesticides. In general, they are less hazardous than chemicals. They are generally less toxic than chemical pesticides, often target specific, have little or no residual effects and have acceptability for use in organic farming.

### Types of New Generation Biopesticides

#### 1. Microbial Biopesticides

These include bacteria, fungi, viruses and protozoa that control pests through infection or toxin production.

- *Bacillus thuringiensis* (Bt) produces endotoxins effective against lepidopteran pests (Bravo *et al.*, 2011).
- Entomopathogenic fungi such as *Beauveria bassiana* infect insects through cuticle penetration.

#### 2. Botanical Biopesticides

Derived from plant extracts, these include compounds like azadirachtin from neem (*Azadirachta indica*), which acts as an antifeedant and growth regulator (Isman, 2006).

#### 3. Biochemical Biopesticides

These include natural substances like pheromones and plant growth regulators that interfere with pest behaviour and reproduction.

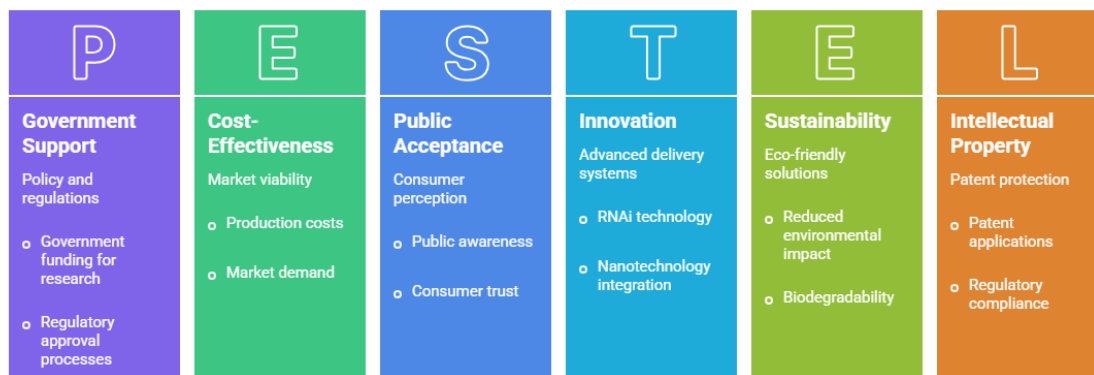
#### 4. RNAi-Based Biopesticides

A cutting-edge approach where double-stranded RNA (dsRNA) silences essential genes in pests, leading to their death. This method is highly specific and environmentally safe (Zotti *et al.*, 2018).

## 5. Nano-Biopesticides

Integration of nanotechnology improves delivery, stability and effectiveness of biopesticides, reducing dosage and environmental contamination (Kah *et al.*, 2019).

### New Generation Biopesticides



### Most common biopesticides

Biopesticide	Type	Target Pest/Disease	Major Crops	Mode of Action
<i>Bacillus thuringiensis</i> (Bt)	Bacterial	Caterpillars (Lepidoptera)	Cotton, cabbage	Produces toxins → destroys insect gut
<i>Trichoderma viride</i>	Fungal	Soil-borne fungi ( <i>Fusarium</i> , <i>Rhizoctonia</i> )	Vegetables, pulses	Antagonism & mycoparasitism
Neem ( <i>Azadirachtin</i> )	Botanical	Sucking & chewing pests	All crops	Antifeedant & growth regulator
<i>Pseudomonas fluorescens</i>	Bacterial	Wilt, root rot diseases	Rice, vegetables	Induces systemic resistance (ISR)
<i>Beauveria bassiana</i>	Fungal	Whiteflies, aphids, beetles	Vegetables, fruits	Infects and kills insects
NPV ( <i>Nuclear Polyhedrosis Virus</i> )	Viral	<i>Helicoverpa</i> , <i>Spodoptera</i>	Cotton, pulses	Infects larvae → death

## Application Methods of Biopesticides

Biopesticides can be applied through different methods depending on the target pest and crop stage. Seed treatment is a common practice where bioagents such as *Trichoderma* and *Pseudomonas* are coated on seeds before sowing. This helps in protecting the seedlings from soil-borne pathogens and promotes early root development. Soil application involves mixing biopesticides with compost or farmyard manure and applying them to the soil, mainly to control root diseases caused by pathogens like *Fusarium* and *Rhizoctonia*.

For above-ground pests, foliar spray is widely used, where biopesticides such as *Bacillus thuringiensis* (Bt) and neem-based formulations are sprayed directly on plant leaves to control caterpillars and sucking pests. Additionally, pheromone traps are used as a behavioural control method, where synthetic pheromones attract insects into traps, helping in monitoring pest population and disrupting their mating cycle. These application methods are essential for maximizing the effectiveness of biopesticides in integrated pest management systems.

## Advantages of New Generation Biopesticides

- **Environmentally safe:** Minimal residual toxicity and reduced pollution
- **Target specificity:** Protects beneficial organisms like pollinators and natural enemies
- **Resistance management:** Lower chances of resistance development
- **Biodegradability:** Rapid degradation reduces persistence in the ecosystem
- **Compatibility with IPM:** Can be integrated with cultural, mechanical and biological control methods

## Challenges and Limitations

Despite their advantages, several constraints limit widespread adoption:

- Short shelf life and sensitivity to environmental conditions
- Slower action compared to chemical pesticides
- Limited awareness among farmers
- Higher initial cost and inconsistent field performance
- Regulatory and commercialization hurdles

## Future Prospects

The future of biopesticides lies in technological integration and innovation:

- Genetic engineering for improved strains
- AI-based pest monitoring and precision application
- Development of stable and cost-effective formulations
- Policy support and farmer education programs
- Integration with climate-smart agriculture practices

### Conclusion

The rise of new generation biopesticides signifies a shift in agriculture towards environmentally sustainable methods. These biopesticides, sourced from natural elements like microorganisms and plant extracts, reduce toxic residues and environmental harm while protecting beneficial species. They are more specific and biodegradable than traditional pesticides, minimizing risks related to bioaccumulation and pest resistance. New innovations, such as RNA interference and nano-formulations, have improved their effectiveness for large-scale use and compatibility with Integrated Pest Management (IPM) systems. However, challenges like short shelf life and farmer awareness hinder adoption. Tackling these issues through research, farmer training and supportive regulations is essential. With climate change and rising demand for safe food, integrating biopesticides is crucial for sustainable agriculture and food security.

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