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Advances in microbial biopesticides for integrated disease and pest management: A review

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ABSTRACT

The injudicious use of chemical pesticides poses a negative impact on crop ecosystem as well as environmental health. To overcome the burden of chemicals, biopesticides have been employed for managing pest and diseases. Biopesticides are one of the vital components of organic and integrated disease and pest management (IDPM) strategies utilized in compatible manner in the field. Moreover, biopesticides are cost effective, eco-friendly, and sustainable in nature. They are numerous tools for accomplishing new sustainable agricultural products. Also, there are different source of biopesticides including botanical and microbial origin. Microbial biopesticides such as Trichoderma spp., Bacillus spp., Aspergillus spp., Beauveria bassiana, Metarhizium anisopliae, Baculovirus (Nucleopolyhedrovirus (NPV) and Granulovirus (GV), Steinernema carpocapsae, Nosema spp. etc. have employed under laboratory and field conditions. Biopesticides are successfully exploited in managing diseases and pests and this paper reviews the current scenario of bioagents, their uses and future prospects and notably for achieving sustainability in agriculture.

Keywords: Biopesticides, ecosystem, disease, pest, sustainable agriculture

INTRODUCTION

Biopesticides are the products of microorganisms or natural products have been utilized for controlling diseases and pests through various mode of action (Tijjani *et al.,* 2016). Biopesticides are non-toxic, ecofriendly in nature made from naturally occurring animals, plants, microbes, or minerals comprising living organisms (natural enemies), their products (phytochemicals, microbial products), or byproducts (semiochemicals) and microorganisms such as *Bacillus thuringiensis*, *Trichoderma*, Nucleopolyhedrosis virus etc. (Mazid *et al.,* 2011, Saikia *et al.,* 2021). Biopesticides boosts the crop production maintaining the sustainable ecosystem (Kumar, 2012; Bora and Bora *et al.,* 2021), while it can substitute or can be integrated with chemical pesticides in sustainable disease and pest management strategies (Anani *et al.,* 2020; Srivastava *et al.,* 2022). In addition, biopesticides are cheap, ecofriendly, specific in their mode of action, sustainable, do not leave residues, and are not associated with the release of greenhouse gases (Borges *et al.,* 2021). These biopesticides can be in the form of phytopesticides (Idris *et al.,* 2022), microbial pesticides (microbial origin; Harish *et al.,* 2021), and nanobiopesticides (nanoparticles produced from biological agents; Abdollahdokht *et al.,* 2022; Pan *et al.,* 2023). Unlike synthetic pesticides, microbial pesticides are specific in action, can be easily sourced without the need for expensive chemicals, and are environmentally sustainable without residual effects (Harish *et al.,* 2021; Hummadi *et al.,* 2021). Phytopesticides have numerous phytochemical compounds that make them exhibit various mode of action. In addition, they are unacquainted with the release of greenhouse gases and enthusiastically minimize the risks to human health compared to the synthetic chemicals (Malahlela *et al.,* 2021; Idris *et al.,* 2022).

From antiquity, the uses of synthetic chemicals have an mitigation activity against diseases and pests for amended crop production. Despite the mitigation consequence of chemicals against diseases and pests, it have negative impacts on soil microorganisms by limiting their plant biota in the production of certain plant growth-promoting traits, such as siderophores and indole-3-acetic acid (Farooq *et al.,* 2019; Kumar and Kumar, 2019). Moreover, synthetic pesticides get inflicted to cause harm to environment and diminish the plant's growth, notably in seed production (Hashimi *et al*, 2020).

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The tremendous application of pesticides leads to the death of aquatic life and water pollution (Kumawat *et al.,* 2009; Kanwar *et al.,* 2013; Jayaraj *et al.,* 2017; Sabarwal *et al.,* 2018; Manfo *et al.,* 2020). Therefore, application of biopesticides indeed a prospective tool as a crucial part of integrated disease and pest management and have been very useful in fostering the sustainable environment. Microbial bioesticides are the largest group of biopesticides that carry biopesticides contain living organisms including entomopathogenic fungi, bacteria, viruses, and protozoa (Carlton, 1993, Bora *et al.,* 2024). Entomopathogenic fungi are among the first organisms to be exploited for the biological control of insect pests. The entomopathogenic fungus *Metarhizium anisopliae* has been revealed as a safe and environmentally friendly substitute to synthetic chemical pesticides (Domsch *et al.,* 1980; Zimmermann, 1993). *Beuveria bassiana,* another EPF was found effective for successful management of two-spotted spider mite, *Tetranychus urticae* (Ullah and Lim, 2015; Basak *et al.,* 2021). Several strains of *Metarhizium anisopliae* and *Beauveria bassiana* have been tested and employed as biopesticides. *Bacillus thuringiensis* is the most widely used biopesticide and *have* proven against Lepidopteran larvae. EPF *M. anisopliae* and *B. bassiana* are effective against agricultural pests such as aphids, leaf hoppers, cut worms, borers and other lepidopteran pests (Erla *et al.,* 2021). Besides insect pest management bioagents like *Trichoderma* spp, *Pseudomonas* spp etc. are widely accepted against plant diseases (Srivatava and Bora, 2023; Bora *et al.,* 2024).

Status of biological control agent (BCA) research and development

Over the past two decades, an urgent need was sparkled for management strategies that are safe to the environment where BCA-based formulations, referred to as biopesticides can play a pivotal role. *Trichoderma* spp., *Pseudomonas* spp., *Bacillus* spp., *Agrobacterium radiobacter*, non pathogenic *Fusarium* spp., *Coniothyrium* spp. and *Aspergillus niger*, *Bacillus thuringiensis* (Bt), *Metarhizium* spp., *Beauveria bassiana*, and Nuclear polyhedrosis virus (NPVs), which are widely used in plant protection (Keswani *et al.* 2015; Mishra *et al.,* 2015, Erla *et al.,* 2022). *Trichoderma* spp. is the prominent bioagent used against major phytopathogens like *Rhizoctonia solani, Fusarium spp, Ralstonia solanacearum*, *Pestalotia* spp. (Bora *et al.,* 2019; Kumari *et al.,* 2022; Rahman *et al.,* 2023). *Trichoderma reesei* based formulation was quite effective against fusarium wilt of banana Tropical Race 4 and bio-immunization technology showed efficacy against the pathogen (Damodaran *et al.,* 2023). *Trichoderma* can control pathogens through hyperparatisitism, antimicrobial metabolites, cell wall degrading enzymes besides outcompeting microbes through active colonization. A vast literature also unveils use of *Bacillus* spp. as growth promoter as well as bioagent against many pathogens (Saikia *et al.,* 2022, Barua *et al.,* 2024). Bora *et al.,* (2023) demonstrated miticidal efficacy of *Bacillus velezensis* against red spider mite and identified the bacterial metabolites responsible as biological miticide. Due to climate change, disease scenario has been changing and to counteract new microbes and consortia are most relevant. It is interesting to note that plants exhibit different microbiome under stress condition (Handique *et al.,* 2024). The endophytic microbes also plays major role in crop health and ward off many pathogens of crops like rice, vegetables and fruit plants (Sharma *et al.,* 2020; Saikia *et al.,* 2020; Bora *et al.,* 2020). Arbascular mycorrhizal fungi have recently gained attention in disease management. In addition, arbascular mycorrhizal fungi (AMF) can play a major role in water and nutrient uptake in host. Cheng *et al.* (2020) recorded stimulation of signal transduction in Trifoliate orange against *Phytophthora parasitica*.

Current Indian status of Biopesticides

The biocontrol concept of plant diseases has been started in India for an extended time (Schmutterer, 1985). The neem tree (*Azadirachta indica*) and its derivatives, such as leaf extract, oil, and seed cake, have been used as fertilizers to minimise the risk of post-harvest loss in storage cereals (Isman, 1997; Brahmachari, 2004). During the 1960s, with a target of judicious use of pesticides in agriculture, the concept of IPM had also arisen (Smith and van den Bosch, 1967). However, in India, a

Table 1: List of some bacterial biopesticides developed and commercialised around the world

Biocontrol Agents	Product Name	Target Pathogens	Crops
Bacillus subtilis QST 713	Cease	*Rhizoctonia solani, Pythium, Phythophora, Fusarium*	Most greenhouse ornamentals and vegetable transplants
Agrobacterium radiobacter K84	Galltrol	*Agrobacterium tumefaciens*	Ornamental nursery stock, soil treatment
Bacillus subtilis GB03	Companion (liquid)	Leaf spots, Powdery mildew, Botrytis, bacterial diseases, *Rhizoctonia solani, Pythium, Phytophthora*	Most greenhouse ornamentals and vegetable transplants
Bacillus subtilis	Kodiak	*Rhizoctonia solani*, *Alternaria* spp, *Aspergillus* spp, *Fusarium* spp.	Cotton and legumes
Gliocladium virens GL-21	Soil gard	*Rhizoctonia solani, Phytium*	Most greenhouse ornamentals, vegetable transplants

major technological advancement in biocontrol has addressed when conventional insecticides failed to control *Helicoverpa armigera*, Spodoptera *litura*, and other cotton pests (Kranthi *et al.,* 2002). Moreover, the awareness about the utilisation of biopesticides among the farmers is enhancing and hence it becomes a very prominent alternative to the chemical pesticides (Pelaez and Mizukawa, 2017).

Biopesticides are registered and regulated under the Insecticides Act, 1968 (Satapathy, 2018). Currently in India, the share of biopesticide is 5% of total pesticide used. It includes 970 registered microbial formulations with the Central Insecticides Board and Registration Committee (CIBRC) of India. Among these products *Trichoderma*, *Bacillus* spp., *Beauveria bassiana*, *Lecanicillium lecanii* and *Hirsutella thompsonii, M. anisopliae, Pochonia chlamydosporia, Purpureocillium lilacinum* are registered and applied against various arthropods and plant parasitic nematodes. Besides these entomopathogenic nematodes are also available in market (Kumar *et al.,* 2019). But, the growth of biopesticide market is slow in India due to low adoption, spurious products and the difficulties in registration process.

Table 2: List of bioinsecticides available in India

Biocontrol Agents	Product Name	Against Pests
Bacillus thuringiensis sub sp. *israelensis*	Tacibio/Technar	Leipdopterous pests
Bacillus thuringiensis sub sp. *kurstaki*	Bio-Bart/ Biolep/Halt	Lepidopterous pests
Baeuveria bassiana	Biowonder/Veera/Bioguard	Coffee-berry borer, diamondback moth, thrips, grasshoppers, whiteflies, aphids, coding moth
Helicoverpa armigera NPV	Helicide/Heligard	Cotton bollworm
Metarhizium anisopliae	Meta-Guard/Biomet/Bio Magic	Coleoptera and lepidoptera, termites, mosquitoes, leafhoppers, beetles, grubs
Spodoptera litura NPV	Spodocide/Spodoterin	*Spodoptera litura*
Pseudomonas fumosoroseus	Nemato-Guard	Whitefly
Pseudomonas lilacinus	Yorker/Bio-Nematon	Whitefly
Verticillium lecanii	Verisoft/Versitile	Whitefly, green coffee bug, homopteran pests

Challenges of biocontrol agents in cropping system

The quality of BCAs and their different formulations and efficiency of the antagonist strain are utmost important. It is measured in terms of inoculum potential (propagules/unit weight and the aggressiveness), shelf life, and ease of application and purity of the formulation. Generally, the biological control formulations available in the market are of very poor quality with meager shelf life (Singh *et al.,* 2012), which demand strict regulation through quality control agencies. Moreover, biological control agents despite of performing well under controlled environments may failure to yield in the field conditions. Further, storage and marketing of microbial biopesticides is another issue that significantly limiting the extensive use of BCAs in today's agriculture. It is a high grade to educate the dealers and users (cultivators) on importance of appropriate storage conditions, shelf life, and mode of action of BCAs. Biocontrol agents show inconsistent results in field for many reasons. The storage conditions, environmental parameters, use of heavy doses of chemicals may interfere with their performance. Therefore, it is imperative to identify BCAs which can thrive in a wide range of soil environmental conditions. Besides these, there are some other restrictions. Most bioagents are host specific and as such they are not broad spectrum. Further, mass production needs sophistication and skill (Rahman *et al.,* 2021).

Future prospects of biopesticides

Although many crops are affected to pest each year, but the emergence of synthetic pesticides have assisted to minimize the yield losses. The exploitation of biological pesticides has increased as a result of the negative impacts of synthetic pesticides. Since biopesticides have proven as good alternative to chemical pesticides, it will be very important to explore them for maximum use in agriculture. Therefore, making grants or capital available for researchers, entrepreneurs, producers, and marketers can help to enhance the production and availability of biopesticides.

Consequently, more research should be carried out to incorporate bio-carriers and other sustainable methods, which can be used to enhance the persistence of biopesticides in the environment. Hence, it is imperative to carry out more research on the compatibility of different biopesticides, which are likely to be used together on the same crop. Furthermore, most research carried out on biopesticides was crucially focussed on yield and growth parameters. The Maximum Residual Limit for pesticides in local markets should be enforced and awareness should be created on the effectiveness of biopesticides, as the farmers can explore them. Awareness of the effects of the indiscriminate use and health effects of biopesticides in humans will also help to promote a good environment and health. Due to the numerous challenges still encountered with the use of biopesticides, the sole use of biopesticides might not be feasible. Therefore, their incorporation with the existing synthetic pesticides will be a better means of preventing crops from pests and ensuring sustainable agriculture.

CONCLUSION

Over the many years, farmers are completely relying on chemical pesticides and utililized expansively in the field. Due to injudicious use of chemicals, resistance problems are elevated and posing harm to ecosystem. Due to these problems, microbial biopesticides are enthusiastically employed for suppressing the diseases and pests of agriculture than hazardous chemicals. The utilisations of biopesticides are rapidly increasing due to their eco-friendly with host-specific nature globally. Biopesticides are sparkling global attention as a cost effective, safer, eco-friendly approach to manage diseases and pest populations. Therefore, biopesticides need to be exploited more precisely and increasing awareness of using biopesticides in order to minimize the utilization of chemical pesticides. Consequently, biopesticides have the potential to bolster sustainability to global agriculture. Furthermore, post harvest diseases with microbe-based technologies; nano biofungicides, antimicrobial metabolites etc. are some domains to be addressed for next generation biopesticide.

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