



Embrace Biopesticides, Cultivate Green Solutions for a Flourishing India!" A review

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Article History	Abstract
Received: 30/09/2023 Revised: 15/10/2023 Accepted: 30/10/2023	In agriculture to prevent crops from pests chemical fertilizer has been used for the longest period of time but the use of chemical fertilizer for the longest period of time has led to concern regarding human health as well as the environment. The extensive use of chemical fertilizers in the era of green revolution has led to pesticide related soil leaching, consumption of pesticide via bioaccumulation, secondary pest infestation. Biopesticides provides eco-friendly alternative to chemical pesticides. Biopesticides are a type of pesticide derived from natural materials, such as plants, animals, bacteria, and fungi, which are used to control pests and manage agricultural or horticultural problems. Unlike conventional chemical pesticides, biopesticides are considered to be environmentally friendly and generally have lower toxicity levels to non-target organisms, including humans. The benefits of using biopesticides include biodegradable, cost effective etc. The use of biopesticides has increased yield at about 5-10% per year. In developing country like India remains significantly dependent on agriculture as a crucial sector of its economy. Agriculture plays a vital role in the country's social and economic fabric, contributing to employment, food security, and rural development. In this review we have discussed regarding current status of biopesticides usage in an Indian scenario.
CC License CC-BY-NC-SA 4.0	Key words: Pest, Biopesticide, Biological Control, Current status, Sustainable Environment.

Introduction

Developing countries like India depends on agriculture to produce for growing population. Indigenous farmers depends solely on chemical pesticides to supply protection to the crops. These chemical pesticides have harmful effect on humans, degrades soil quality, disrupts biodiversity of soil and pests become quickly immune to pesticides. additionally, crops containing pesticides over permissible limits creates hindrance in export of crops thus creates a disruption in trade. (Birch et al., 2011) To protect the environment against harmful effects of chemical fertilizer biopesticides are used. The scientific definition offered by the United States Environmental Protection Agency (EPA), can be categorized into three main groups:

(i) naturally-occurring biological chemicals which acts via non-poisonous mechanisms

- (ii) microbial entomopathogens
- (iii) genetically modified genes incorporated in plant cells which provides protection against pests.

Biopesticides are generally used to protect the environment and prevent secondary pest invasion. (Kumar et al., 2021). In agronomy bacterial and arthropod population is preferred than less biodiversity of soil. Microbial pesticides are represented by bacteria, virus, fungi, protozoa and nematodes. In last few years extensive research has been conducted on biopesticides led to development of various microbial biopesticides. (Chakraborty et al., 2021) (Figure 1)

In this review we have discussed on different eco friendly biopesticides available for agriculture and current status of these biopesticides available for agriculture and current status of these biopesticide usage in Indian scenario Biological Pest control via Integrated Pest Management System.

Development of chemical pesticides helped in reduction of pathogenic attacks on crops but in turn it led to resistance of pests towards chemical pesticides and led to secondary pest invasion. The new perspective developed to control pathogenic attack on crops is called 'integrated pest management' (IPM). (Frank et al., 2023) The term integrated incorporate preventive actions (like organic, inorganic, indigenous and acquired techniques) are taken into consideration as various techniques are taken into consideration the chances of survival of pests is likely less. IPM is a five step process such as determination of type and population size of specific pest Identification of Pest-pathogen Determination of financial and esthetic impairment caused by specific pests If the level of impairment crosses the borderline then proper actions via organic, inorganic, indigenous and acquired techniques are implemented Rate of success is calculated with implemented techniques. (Frank et al., 2023) In this article we have focused on importance of microbial bio-pesticides usage instead to chemical counterparts and their current utilization status in Indian subcontinent.

Phytopesticides

Different plant oil extracts and essential oils have been used as biopesticides for a long period of time. These entice, drive away, aspirate, detects host plants for specific pests, destroys larvae and eggs of pests and kills pests which feed on plants and crops. (Tripathi et al., 2009)

Families of plants which contains biologically active compounds which provides protection towards crops against pests are Myrtals, Laurals, Sapindales, Laminariaceae, Asteraceae. (Gakuubi, 2016) These are easily attainable and cheaper in price. Secondary metabolites, such as steroids, alkalies, terpenoids, phenolic, flavins, and resins have pesticidal effects on bacteria, fungus, virus, nematodes etc. Biopesticides are known to action specific species of pests so, it can be assumed that a particular biopesticide can have limited action only. (Ahmad et al., 2017) Based on the biopesticide and pest, they can repel, inhibit, denature protein, and shows other effects. Biopesticides such as pyrethrin acts on nerves of insects eventually leading to paralysis and death. Neem shows pesticidal properties like repelling pests, disruption in reproductive ability of pests, causes porosis in haemocoel. (Geraldin et al., 2020) (Table 1)

Though phytopesticides have many advantages these are species specific and acts on a single species at a time so if crops are affected by more than one species of pest it requires several phytopesticides and their activity vastly depends on the quality of active ingredients so phytopesticides needs to be collected during morning so phytochemicals are active. Due to all these disadvantages microbial biopesticides are preferred form of biopesticides.

Microbial biopesticides

Microbial biopesticides are a type of pest management tool that use living microorganisms, such as bacteria, fungi, viruses, or protozoa, to control pests in agriculture, forestry, and other settings. Unlike traditional chemical pesticides, microbial biopesticides offer a more environmentally friendly and sustainable approach to pest control. (Chandler et al., 2011) They can be used to target a wide range of pests, including insects, weeds, and plant diseases. (Chandler et al., 2011)

These pesticides acts species specific so does not affects the biodiversity of the soil and these pesticides have shorter life span so there are no residues of pesticides left in crops which is safe for consumption for both humans and animals. Microbial pesticides can be mass produced at a very low cost and several species of micro organisms can be used as a fertilizer at a time which makes it versatile in nature.

Bacteria

Bacterial species and their association with invertebrates have been studied for a long period of time. *Bacillus Thuringiensis* has been used in agronomy for the longest period of time. (Ayilara et al., 2023) The pesticidal property of *Bacillus thuringiensis* is the endotoxin (Cry and Cyt) is attached to crystal bodies produced during

sporogenesis and some of which are formed and released during the growth phase of endospore. Due to variation in number of receptors of endotoxin it gets attached to different receptors in the midgut of pest. So, based on the variation of attachment of endotoxin the biopesticidal properties varies. (Xiao et al.,2019)

It can be concluded that a specific strain of Bt. Gene is only effective towards a narrow range of pests. When pests ingest these δ endotoxins it binds to the receptors of midgut and causes porosis which results in change in epithelial barrier permeability and leads to disruption of intestinal mucosal barrier and leads to septic infection in the pest due to bacteria and leads to death. (Xiao et al.,2019) Bacteria like *A. tumefaciens* consists of DNA containing chromosomes and tumor inducing plasmid (Ti-plasmid). Tumour inducing plasmid carries fragments of (Transfer DNA) that can be embedded in the plant genes followed by bacterial infection. A particularly selected gene, like the Bt δ endotoxin, is replicated in the transfer DNA of tumour inducing plasmid. After inoculating Bt δ endotoxin in the cells of corn, transfer DNA which carries Bt genome gets embedded in the plant gene. The corn plant which regenerates express Bt δ endotoxin. (Gordon et al.,2013)

Betaproteobacteria is a bacterial species which acts as an active biopesticidal agent. *Burkholderia rinojensis* is a strain of insect which is detected recently and developed into commercial biopesticide which acts via consumption or by exposure towards various arthropods which ingest or suck on agricultural produce. The biopesticidal properties depend on various metabolic activities and commercial products are based on heat-killed cells and spent fermentation media. *Chromobacterium subtsugae* is another betaproteobacterium which is commercialized whose metabolic activities shows biopesticidal activities towards a large spectrum of arthropods specially towards various species like *Lepidoptera*, *Hemiptera*, *Coleoptera*, and *Diptera*. (Ruiu et al.,2018) (Table 2) (Figure 2)

Pathogen containing nematodes enter into the host via openings like anal or oral cavities and release symbiotic bacteria in the haemocoel. The pathogen causes porosis in the host and releases viral components and toxic substances inside the host which weakens the host and the metabolites produced by the nematode create a suitable environment for the nematode to reproduce and develop. *Photorhabdus* and *Xenorhabdus* produce toxic complexes and other viral complexes towards arthropods which shows toxic effects towards consumption. Various in vitro and in vivo nematode biopesticides have been developed in small scale and in large scale industries. Though the quality of formulations have huge effect on the effectiveness of the biopesticide. (Kenney et al.,2016)

Entomopathogenic nematode (EPN) species family Heterorhabditidae and Steinernematidae forms obligate and mutual parasitic association with pathogenic bacteria like *Photorhabdus luminescens* and *Xenorhabdus bovienii* respectively. (Schurkman et al.,2021)

Fungi

A broad range of fungi is included in the groups of biopesticides which shows different mode of actions and different working principle. The infection proceeds when the conidial spores germinate and come in contact with the host. With the combination of action of enzymes and via penetration the fungal spore enters inside the host and mycelia forms inside the host forming a number of conidiophores. During growth fungus produces a number of metabolic substances favoring in development or helps in production of toxins. (Vega et al.,2012) (Table 3) (Figure 4)

The host which gets affected due to fungal spore via biochemical and penetrative actions dies usually and the conidia or spores develop outside the cadaver of host so it can spread in ecosystem. The infection in host is triggered via conidia or spores which requires specific conditions like temperature humidity and other parameters to develop. Fungal entomopathogens include species like *Beauveria bassiana* (Balsamo-Crivelli) Vuillemin, *Isaria fumosorosea* Wize, *Metarhizium anisopliae* (Metschnikoff) Sorokin and *Lecanicillium lecanii* (Zimmerman).

(Srinivasan et al.,2019). *Beauveria Bassiana* is most marketed biofungicide. The conidia penetrate the cuticle and reach haemocoel of pests and release hydrolytic enzymes, chitinase, proteolytic enzyme, and lipolytic enzyme and disintegrate the endocuticle for more conidia production. Hyphea which passes through the epidermal layer and intrudes inside hemocoel of the insects and secretes toxic substances, such as oosporein, beauvericin, beauverolides, and tenellin most of them suppress immune system or directly destroy haemocoel. (Srinivasan et al.,2019). *Trichoderma* sp., *Paecilomyces* sp, are most commonly used biofungicide. *B. bassiana* have shown different levels of toxicity against different pests, so various levels of formulations are used against different pests. (Islam et al.,2023) Several arthropods are associated with the spread of spores. Though there is development of various fungal biopesticides but their actions are species specific a fungal biopesticide can act on narrow range of pests. *Metarhizium anisopliae* is known to have working range over a broad range of pests. (Aw et al.,2017) (Table :3) (Figure:3)

Virus

Pathogenic DNA virus Baculovirus associated with arthropods showed biopesticidal properties. The virus carries infected crystalline particles to the host cells. On the basis of crystalline particles baculoviruses are categorized into: nuclear polyhedrosis virus, it is a double stranded DNA structure capsid is rod shaped and develops into nucleus of cell and granulo virus containing coiled double stranded DNA one molecule and rod shaped enveloped virion. In the cytoplasm another polyhedral shaped crystalline structured double stranded RNA virus is present. (Clem et al., 2013) The host needs to ingest the baculovirus in order the infection to spread. In the gut of the host where there is optimum conditions like pH and other factors a particular virus known as occlusion derived virus is released which interconnect with the micro villi of epithelial cells via the action of proteins called phytochrome interacting factors. (Haase et al., 2015) Within the nucleus of the gut cells a second group of viruses called budded viruses are formed so that the virus can successfully spread throughout the host. Progressively as the infection spreads throughout the host and eventually the host dies and the cadaver liquefies aids its spreading throughout the environment. Viral infections in host also induces behavioral switch in hosts affecting their gene expression. (Sun et al., 2015) Based on their mode of action baculoviruses are only active towards pests ingest (e.g: caterpillar) the viruses. Due to their low stability in the ecosystem baculoviruses have high production cost and it needs to be reproduced within the host for the infection to spread. Market range of these pesticides are quite narrow and works on a specific niche of pests only. (Sun et al., 2015) (Table:4) (Figure :4)

Current status of biopesticides utilization in Indian subcontinent

In India there are several biopesticides producing companies of which some are private and mostly government owned. Central IPM units, Indian Council of Agricultural Research institutions or State Agricultural Universities, Department of Biotechnology funded research organizations and various other laboratories conduct research for the development of biopesticides. (Fenibo et al., 2022) .70% biopesticides are produced by public sectors. Biopesticides occupies 9% of total pesticide market it is estimated that by 2050 biopesticide will occupy 50% of pesticide market. It is estimated there is 2.5% is the growth rate of total biopesticide market. Though biopesticide industry is still not developed in India and smaller comparative to chemical pesticide market though it was supported by National Farmers policy (2007) (Thokre et al., 2014). India has shown growth in use of biopesticides in last few years. From 1994-1995 biopesticide use rose to 83 metric tons and from 1999-2000 biopesticide use increased to 686 metric tons 8110 MT in 2011–2012. While *Bacillus Thuringiensis* use rose to 71 MT from 41 MT during the same time. According to PPQS statistics there is 40% rise in use of pesticides between 2014-2015 and 2018-2019 8645 metric tons in 2020–2021. (Paul et al., 2022). In India, the Central Insecticides Board and Registration Committee (CIBRC) have 970 biopesticides registered with it. (Nayak et al., 2021) Bacteria biopesticide have 29 % fungal biopesticide have 66% varial biopesticide have 4% and plant biopesticides have 1 % of total biopesticide usage. Major market share is led by Fungal Biopesticide *Trichoderma* sp followed by bacterial biopesticide *Bacillus thuringiensis* and, viral biopesticide, NPV virus respectively.

Discussion and future prospects of biopesticides

Research on microbial pesticides requires further development for the biopesticidal market in the future. Though there are various scientific researches regarding microbial biopesticides but there are very few well organized reports available. Collaboration among research institutes and industry is required for the development of biopesticides in large scale. At present agriculture depends on both chemical and organic fertilizers. However, with development with the biofertilizer and introduction of new technology (like nanotechnology) there would be a possibility in industrial scale production of bio pesticides. (Paul et al., 2022) Nanotechnology is used nowadays to develop pesticides. Nanopesticides are small particles containing active ingredients of pesticides or structures containing properties of pesticides, embedded within matrix and enclosed within a capsule which activates due to enzymatic reaction. These are 2D or 3D structures carrying active ingredients of biopesticides. (Fenibo et al., 2022) Nanopesticides are generally used to increase nutrient availability of soil, protect the actives of biopesticides from bio degradation. It controls pests, pathogens which harm crops, weed. These are available in gel, capsule, fiber and sphere form. (Ayilara et al., 2023) In recent years nanopesticides have gained popularity, these are used as fertilizers pesticides. The activity between plants and active ingredients of biopesticides are studied via microscopic or fluorescent spectrometric method. The properties of nanopesticides are determined via their chemical composition, physio-chemical changes. The main functions of nanobiopesticides are to decrease the loss of actives, increase solubility protect crops

from infestation, prevents plant injury etc. (Ayilara et al., 2023). Due to extended surface area and particle size functioning mechanism of functioning of nanopesticides varies from conventional biopesticides. Due to small size. Nanoparticle administration comparatively reduces the drift and percolation of the soil and the actives are required in a smaller amount in a particular area, and the bio actives are provided to the crops in requisite concentration for a long time period. Nanopesticides can be of various forms like emulsion, capsule and inorganically engineered (like oxides of metals, clay etc.) and can be further modified to better form which increases the potency of pesticides which already exists and reduces toxic effect of pesticides in environment or both. (Ayilara et al., 2023) (Table: 5)

Throughout the years a lot of crops have been lost throughout the years and with the development of chemical pesticides but with the use of chemical pesticides quality of soil has been degraded and soil biodiversity has been lost. With the advent of biopesticides these problems have been solved. Though their availability is low which causes problem to both producers and consumers. Shelf life of these biopesticides are short and requires special temperature conditions to maintain storage. (Keswani et al., 2016) So, shelf life needed to be increased. Biopesticides have no actives left in crops so it is quite advantageous but as it does not remain in crops for longer period of time it may not protect crops for a longer period of time. Hence more research needed to be carried out to protect the crops for a longer period of time. (Keswani et al., 2016) The enforcement of integrated pest management system further strengthen the development of market of biopesticides. Development of microbial pesticides and other technologies like nanopesticide is leading to development of more viable pesticides.

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TABLES

TABLE 1: PHYTOPESTICIDES

Source Plants	Parts Used	Secondary Metabolites	Target Pests	Reference
Goat weed	Leaves	Precocenes	Red cotton bug	(Rioba et al.,2017)
Soybean	Pod	Paethenin	Tobacco caterpillar	(Thokre et al.,2014)
Sweet Basil	Leaf oil	Clerodsnes	Milkweed bug	(KUMAR et al. ,2022)

TABLE 2: BACTERIAL BIOPESTICIDES

Bacteria used as biopesticide	Target Pests	Benefited Crop	Reference
<i>B. thuringiensis kurstaki</i>	Diamondback moth	Cabbage	(Legwaila et al.,2015)
	Cotton ballworms	Cotton	(Paramasiva et al.,2014)
	Cotton ballworms	Cotton	(Anilkumar et al.,2008)
	Lepidopteran caterpillar	Cotton, Castor, Tomato	(Anil et al.,2017)
<i>B.Thuringiensis galleiae</i>	Tobacco Caterpillar, leaf folder	Cotton, Rice, Cabbage	(Anil et al.,2017)

TABLE 3: FUNGAL BIOPESTICIDES

Fungus	Target Pests	Reference
<i>Verticillium lecanii</i>	Whitefly, thrips and apides	(Aqueel et al.,2013)
<i>Metarhizium anisopliae</i>	Termites	(Aw et al.,2017)
<i>Metarhizium anisopliae</i>	Locusts	(Aw et al.,2017)
<i>Beauveria bassina</i>	Coffee Berry borer	(Wraight et al.,2005)
<i>Beauveria bassina</i>	European corn borer	(Wraight et al.,2005)
<i>Trichoderma chilonis</i>	Early shoot and stalk borers	(Wraight et al.,2005)

TABLE 4: VIRAL BIOPESTICIDES

Virus	Target pests	Mortality rate	Reference
HZNPV	Corneal worm	90-96	(Dhaliwa et al.,2007)
SINPV	Tobacco caterpillar	95	(Mishra et al.,2020)
HaNPV	Tomato fruit borer	90.60	(Byasigideri et al.,2022)
AgNPV	Velvetbean caterpillar	80.0	(Dhaliwal et al.,2007)
SNPV	Tomato fruit borer	Effective control	(Byasigideri et al.,2022)

TABLE 5: TYPES OF NANOPESTICIDES

Type	Relationship with Nano	Active ingredient	Reference
Nanoemulsion	Actives embedded in nanoscale oil droplets float in aqueous solution	Neem oil, Permethin	(Wadhwa et al., 2022)
Nanocapsule	Actives embedded in nano solution	Lansiumamide B	
Nanogel	Nano particles embedded in gel	Copper, Essential oil	
Nanofibres	Distributed throughout the fibers	Thiametoxam	
Liposomes	These are nano particles	Etopenprox	

FIGURES

FIGURE: 1: Mechanism of action of biopesticides

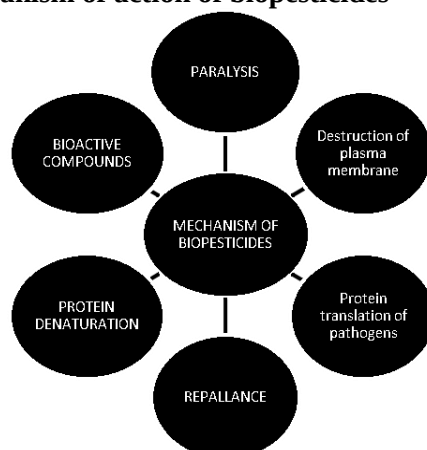
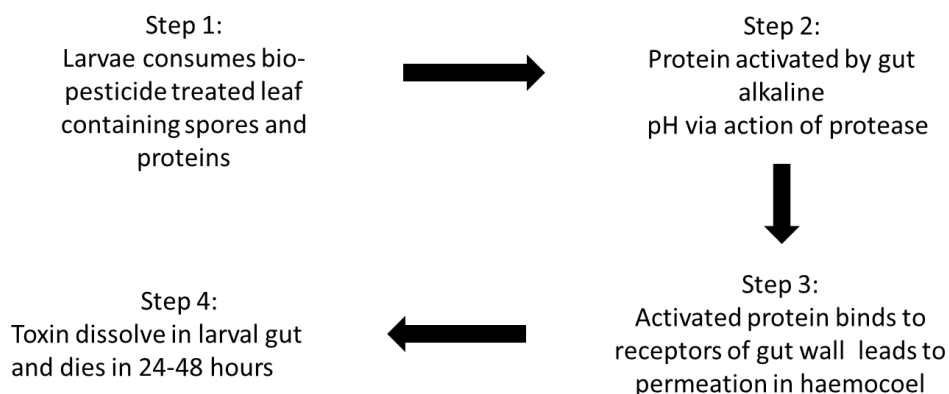
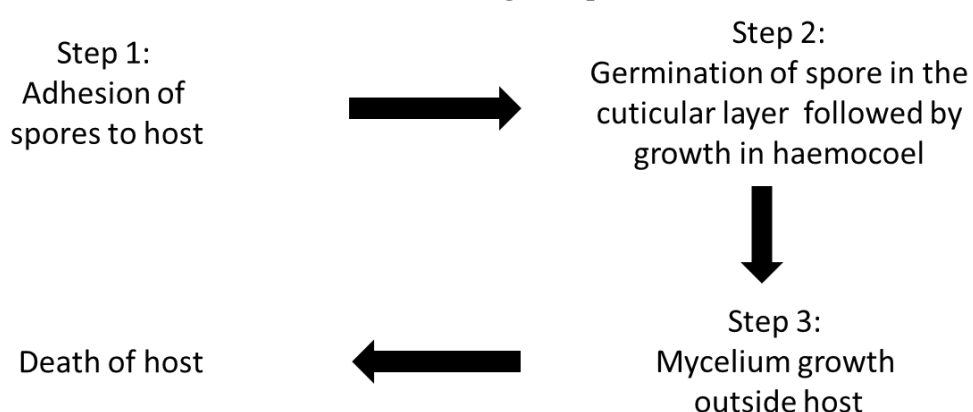


FIGURE :2 : Mechanism of action of bacterial biopesticides**FIGURE :3 : Mechanism of action of fungal biopesticides****FIGURE :4 : Cyclic mechanism of action of viral bio-pesticides**