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Biopesticides: An alternate to chemical pesticides

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Abstract
Chemical fertilizers and pesticides are continuously accumulating in the environment, causing pollution, harming the ecosystem and inflicting diseases at alarming levels. Pesticides being used in agricultural tracts are released into the environment and come in contact with human and livestock directly or indirectly affecting their lives (Kachhawa, 2017).
In India, the first report of pesticide poisoning was documented from Kerala in 1958, where more than 100 people died after consuming wheat flour contaminated with parathion. One instance occurred in Bhopal, where more than 5,000 deaths resulted from exposure to accidental emissions of methyl isocyanate from a pesticide factory (Kumar *et al.*, 2013).
Biopesticides or biological pesticides offer an ecologically sound and effective solution to pest problems. According to United States Environmental Protection Agency (EPA), Biopesticides are certain types of pesticides derived from natural materials such as animals, plants, bacteria and certain minerals. Thus, Microbial Pesticides, Biochemical pesticides, Plant-Incorporated Protectants (PIPs) and beneficial insects comes under the Biopesticides (Osman *et al*., 2015)
The global Biopesticide market is anticipated to raise in the coming years due to high demand for ecofriendly agricultural treatment products. Governments of various regions are implementing rules to adopt ecofriendly products for agriculture. The rise in trend for organic food is also leading to the rise of global Biopesticide market (Kumar and Singh, 2015).
Biopesticides are an important tool for managing the increasing concern over pesticide residues in food and problem of pest resistance against chemical pesticides. Therefore, adoption of Biopesticides for crop protection is increasing in demand so as to discourage chemical pesticides that harm ecology and human and animal health.

Keywords: Biopesticides, microbial pesticides, biochemical pesticides, plant-incorporated protectants (PIPs), beneficial Insects

Introduction
A pesticide is any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest. Pesticides have been preferred due to the benefits they provide in agriculture, particularly by protecting crops from pest damage. The pesticides cover a wide range of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides etc. First synthetic pesticides was used in 1940. The production of pesticides started in India in 1952 with the establishment of a plant for the production of BHC (Benzene Hexa Chloride) near Calcutta (Mathur, 1999) [15] and India is currently the world's 4th largest producer of agrochemicals (IBEF, 2018) [9].
Chemical fertilizers and pesticides are continuously accumulating in the environment, causing pollution, harming the ecosystem, and inflicting diseases at alarming levels. Pesticides being used in agricultural tracts are released into the environment and come in contact with human and livestock directly or indirectly affecting their lives (Wadhwani and Lall, 1972) [26]. Human and livestocks are exposed to pesticides found in environmental media (soil, water, air and food) by different routes of exposure such as inhalation, ingestion and dermal contact. Exposure to pesticides results in acute and chronic health problems as they are designed to adversely affect living organisms (Hollingworth *et al.*, 1995) [8].
In India, the first report of pesticide poisoning was documented from Kerala in 1958, where more than 100 people died after consuming wheat flour contaminated with parathion. One instance occurred in Bhopal, where more than 5,000 deaths resulted from exposure to accidental emissions of methyl isocyanate from a pesticide factory.
Pesticides lead to direct poisoning of species and can cause major population declines which threaten rare species. In Netherland, a typical arable field bird like the skylark is threatened

with extinction because of the lack of wild plants and heavy pesticide use. In Germany, over 130 plants found near farmland are endangered or have vanished (Kumar *et al.*, 2013) [14].

Uncontrolled use of chemical pesticides degrades soil and causes groundwater pollution which has resulted in nutritionally imbalanced and unproductive lands. Therefore, it is very essential to identify alternatives to chemical pesticides for plant disease management without eschewing the agricultural productivity and profitability. Thus, an ecofriendly alternative is the need of the hour. Biopesticides or biological pesticides offer an ecologically sound and effective solution to pest problems.

According to United States Environmental Protection Agency (EPA), Biopesticides are certain types of pesticides derived from natural materials such as animals, plants, bacteria and certain minerals. Plant growth regulators (PGRs), which exhibit no pesticidal activity but instead can promote, inhibit or modify the physiology of plants, are also regulated by the EPA as Biopesticides (Mishra *et al*., 2014) [17].

Biopesticides can be employed in agricultural use for the purposes of insect control, disease control, weed control, nematode control etc. These Biopesticides are classified in following types -

Types of Biopesticides

A. Microbial pesticides
B. Biochemical pesticides
C. Plant-Incorporated Protectants (PIPs)
D. Beneficial Insects (Osman *et al.*, 2015) [20]

A. Microbial Pesticides

Microbial pesticides are products derived from various microorganisms (e.g. bacterium, fungus, virus or protozoan) that are used as an active ingredient to control pests. Microbial products may consist of the organisms themselves and/or the metabolites they produce. They can control many different kinds of pests, although each separate active ingredient is relatively specific for its target pest.

These microbial pesticides are of following types

1. Bacteria
2. Viruses
3. Fungi
4. Protozoa
5. Nematodes

A (I) Bacteria

More than 90 species of naturally occurring, insect-specific bacteria have been isolated from insects, plants, and the soil. *Bacillus thuringiensis* or BT is the species that has been most successfully developed as a microbial insecticide. It is primarily a pathogen of lepidopterous pests like American bollworm in cotton and stem borers in rice. When ingested by pest larvae, BT releases toxins which damage the mid gut of the pest, eventually killing it. Main sources for the production of BT are the strains like:

Bacillus thuringiensis var. kurstaki
Bacillus thuringiensis var. galeriae
Bacillus thuringiensis var.dendrolimus. (Osman *et al.*, 2015) [20]

A (II). Viruses

Baculoviruses are a family of naturally occurring viruses known to infect only insects and some related arthropods. These are target specific viruses which can infect and destroy a number of important plant pests. They are particularly effective against the lepidopterous pests of cotton, rice and vegetables. Their large-scale production poses certain difficulties, so their use has been limited to small areas.

These viruses are applied directly to the plants infested by Hymenopteran, dipteran or lepidopteran insects. These virus forms are eaten by larvae of insect pests. In the midgut of larvae, protein capsules of viruses are dissolved and virions are released. These virions infect the host cells and replicate which results in formation of new virus particles. These virus particles infect more number of cells in host body which ultimately causes death of the larvae and finally virions are released in environment (Nicholson, 2007) [19].

A (III). Fungi

Entomopathogenic fungi are a group of fungi that kill an insect by attacking and infecting its insect host. These fungi are identified as a promising biocontrol agent in the regulation of insect pest population without harming the non-target pests. Trichoderma is a member of ascomycetous fungi found in all soil types with the known telomorph Hypocrea. Several Trichoderma species have been found to have a mutualistic endophytic relationship with several plant species, and have the ability to behave as biocontrol agents against fungal diseases of plants.

Mycoparasitism i.e. the ability to attack other fungi and utilize their nutrients is a process that consists of different events began with recognition of the host fungi followed by attack, penetration and killing them. During these processes, trichoderma produces cell wall degrading enzymes (cellulases, chitinases etc.) that degrade cell wall of the host fungus and kills it (Pucheta *et al*., 2016) [21].

A (IV). Protozoa

Entomopathogenic protozoans are extremely diverse group of organisms comprising around 1000 species attacking invertebrates including insect species and are commonly referred as microsporidians. They are generally host specific and slow acting, producing chronic infections with general debilitation of the host. The spore formed by the protozoan is the infectious stage and has to be ingested by the insect host for pathogenicity. The spore germinates in the midgut and sporoplasm is released invading the target cells causing infection of the host. The infection results in reduced feeding, vigour, fecundity and longevity of the insect host. Only few species has been moderately successful for eg. *Nosema pyrausta* is a beneficial microsporidian that reduces fecundity and longevity of the adults and also causes mortality of the larvae of European corn borer (Kachhawa, 2017) [11].

A (V). Nematodes

Entomopathogenic nematodes are soft bodied, nonsegmented roundworms that are obligate or sometimes facultative parasites of insects. Entomopathogenic nematodes occur naturally in soil environments and locate their host in response to carbon dioxide, vibration, and other chemical clues (Kaya and Gaugler, 1993) [12]. Entomopathogenic nematodes fit nicely into Integrated Pest Management or IPM, programs because they are considered nontoxic to humans, relatively specific to their target pests, and can be applied

with standard pesticide equipment (Ilan *et al*., 2006) [10].
Heterorhabditidae and Steinernematidae are two nematode species which have been effectively used as biological insecticides in pest management programs (Grewal *et al*., 2005) [6].
The juvenile stage penetrates the host insect via spiracles, mouth, anus, or in some species through intersegmental membranes of the cuticle, and then enters into the hemocoel **(**Kachhawa, 2017) [11]. Both Heterorhabditis and Steinernema are mutualistically associated with bacteria of the genera Photorhabdus and Xenorhabdus, respectively (Ferreira and Malan, 2014) [5]. The juvenile stage release cells of their symbiotic bacteria from their intestines into the hemocoel. The bacteria multiply in the insect hemolymph, and the infected host usually dies within 24 to 48 hours. After the death of the host, nematodes continue to feed on the host tissue, mature, and reproduce. The progeny nematodes develop through four juvenile stages to the adult. Depending on the available resources, one or more generations may occur within the host cadaver, and a large number of infective juveniles are eventually released into environment to infect other hosts and continue their life cycle (Kachhawa, 2017) [11].

B. Biochemical Pesticides

Biochemical pesticides are naturally occurring compounds characterized by a non-toxic mode of action that may affect the growth and development of a pest and its ability to reproduce.
Biochemical pesticides are of following types

1. Insect Growth Regulators (IGRs)
2. Plant Extracts
3. Pheromones
4. Oils
5. Pyrethrins

B (I) Insect Growth Regulators (IGRs)

A new approach to insect pest control is the use of substances that adversely affect insect growth and development. These substances are classified as “insect growth regulators’’ (IGRs) owing to their effects on certain physiological regulatory processes essential for normal development of insects or their progeny. They are quite selective in their mode of action and potentially act only on target species.
These biochemicals regulate the growth of the insects with a unique mode of action. They prevent insects to reach a reproductive stage, thereby reduces the expansion of pest populations. The direct impact of IGRs on target pests combined with the preservation of beneficial insects and pollinators aids growers in maximizing yield and product quality.
These insecticides can be grouped according to their mode of action as:

- Hormonal IGRs
- Chitin synthesis inhibitors

Hormonal IGRs typically work by mimicking or inhibiting the juvenile hormone (JH), one of the two major hormones involved in insect molting. IGRs that mimic JH can produce premature molting of young immature stages, disrupting larval development. IGRs can inhibit moulting in the insects.
Chitin synthesis inhibitors regulate the growth of insects by preventing the formation of chitin, a carbohydrate needed to form the insect's exoskeleton. The inhibitors prevent the new exoskeleton to form properly, causing the insect to die. Chitin synthesis inhibitors can also kill eggs by disrupting normal embryonic development (Alam, 2000) [1].

B (II). Plant Extracts

Many plants have developed natural, biochemical mechanisms to defend themselves from weed, insect and fungal attacks. These products act as insect growth regulators, feeding deterrents, repellents, and confusants. Azadirachtin and several other chemicals are obtained from neem tree *(Azadirachta indica)* that affects the reproductive and digestive process of a number of important pests. Recent research carried out in India and abroad has led to the development of effective formulations of neem, which are being commercially produced. As neem is non-toxic to birds and mammals and is non-carcinogenic, its demand is likely to increase. Neem based insecticides are non-toxic to humans and pests usually do not become resistant to these pesticides.
Root-knot nematode is the most important nematode pest of both tropical and sub-tropical region of crop production. This nematode affect more than 2000 plant species including herbaceous, wood plants of mono and dicotyledons etc. Crude and refined neem formulations have been tested against these nematodes. The crude neem formulations are neem leaves and oil cake while the refined one is aza-dirachtin. It has been investigated that application of these two formulations reduces the number of eggs and egg mass when used as nematicides.
Different molecular techniques have been used to determine the effect of azadirachtin at cellular and molecular level. It has been shown that azadirachtin acts on the mitotic cells and blocks the microtubule polymerization. It has been revealed that the anti-proliferating effect of azadirachtin is due to blocking of cell cycle and induction of apoptosis (Ruiu, 2018) [22].

B (III). Pheromones

Pheromones are a class of chemicals that insects and other animals release to communicate with other individuals of the same species. These pheromones can be used as biopesticides and work in following way:
Pheromones can be used to remove large numbers of insects from the breeding and feeding population by mass traping. Massive reductions in the population density of pest insects ultimately help to protect resources such as food or fiber for human use. Mass trapping has been explored with pine bark beetles and has resulted in millions of insects attracted specifically into traps and away from trees. Relatives of bark beetles called ambrosia beetles have been mass trapped from log sorting and timber processing areas throughout British Columbia. These trapping operations have reduced damage to the wood in raw logs and newly cut boards. Mass trapping has also been used successfully against the codling moth, a serious pest of apples and pears. Another common example of mass trapping involves yellowjackets, which is a pest of ornamental plants.
Pheromones can disrupt mating in populations of insects. This has been most effectively used with agriculturally important moth pests. In this scenario, synthetic pheromone is dispersed into crops and the false odour plumes attract males away from females that are waiting to mate. This causes a reduction of mating, and thus reduces the population density of the pests. In some cases, the effect has been so great that the pests have been locally eradicated (Seybold, 1998) [23].

B (IV). Oils

Oils have been used as pesticides for centuries and are some of the most effective, safe alternatives to synthetic insecticides and fungicides. Most oil based products sold as pesticides are regulated by the Environmental Protection Agency (EPA) under the Federal Insecticide, Fungicide and Rodenticide Act. These include oils distilled from petroleum (also known as horticultural or mineral oils) and oils extracted from plants and animals. Most oil-based pesticides are used for insect control; but in many cases oil products also have fungicidal properties.

Regardless of the source or type, all oil-based products have a similar mode of action. Insecticidal oils kill insects on contact by disrupting gas exchange (respiration), cell membrane function or structure. Some plant oils that contain sulfur compounds, such as neem oil, may possess additional fungicidal activity compared to petroleum oils. Oil-based pesticides have low residual activity and must be sprayed directly on the insect or mite. To combat plant fungal pathogens, oils generally must be applied prophylactically prior to infection. Repeated applications of oils may be needed to achieve desired levels of control. Oils are most effective against soft-bodied arthropods. They are most commonly used against mites, aphids, whiteflies, thrips, mealy bugs and scale insects (Bogran *et al*., 2006) [2].

B (V). Pyrethrins

Pyrethrins are pesticides found naturally in some Chrysanthemum flowers. They are a mixture of six chemicals that are toxic to insects. Pyrethrins are commonly used to control mosquitoes, fleas, flies, moths, ants, and many other pests. Pyrethrins are generally separated from the flowers. However, they typically contain impurities from the flower. Whole, crushed flowers are known as pyrethrum powder. Pyrethrins have been registered for use in pesticides since the 1950's. They have since been used as models to produce longer lasting chemicals called pyrethroids, which are man-made.

The pyrethrin and pyrethroid insecticides affect both the peripheral and central nervous systems of insects. They initially stimulate nerve cells to produce repetitive discharges and eventually cause paralysis, an effect similar to, but more pronounced than that of DDT (Davies *et al*., 2010) [4].

C. Plant-Incorporated Protectants (PIPs)

Plant-Incorporated Protectants are the genes and proteins, which are introduced into plants by genetic engineering. They allow the genetically modified plant to protect itself from pests, like certain insects or viruses. These self-made pesticides are called "plant-incorporated protectants" (PIPs). PIP-producing crops are sometimes called "genetically modified" (GM) or "genetically engineered" (GE). For example, some plants produce insect-killing proteins within their tissues. They can do this because genes from *Bacillus thuringiensis* were inserted into the plant's DNA. Some of the crops that can be made to produce PIPs are corn, soybeans, cotton, potatoes and plums (Nicholson, 2007) [19].

D. Beneficial Insects

Human cultures and civilizations have been maintained in countless ways through these beneficial insects, they regulate the pest population of many harmful pest species, produce natural products, and they also dispose the waste and recycle the organic nutrients. The generalized intensification of agriculture and the use of broad-spectrum pesticides decrease the diversity of natural enemy populations and increase the likelihood of pest out breaks. Indeed, pesticide use has been shown to be associated with a large decrease in natural pest control services. Thus, enhancement of agro ecosystem appears to be one of the best ways in which we can decrease the use of chemical pesticides for pest and disease control and it will increase the sustainability of crop production. These beneficial insects act in following ways:

1. By preying on pest insects
2. By parasitizing pest insects(Parasitoids)

1. By preying on pest insects

Predators catch and eat their prey. Some common predatory arthropods include ladybird beetles, carabid (ground) beetles, staphylinid (rove) beetles, syrphid (hover) flies, lacewings, minute pirate bugs, nabid bugs, big-eyed bugs, and spiders etc. Prey on harmful insects of plants and there by decreases pest population.

2. By parasitizing pest insects (Parasitoids)

Parasitoids (sometimes called parasites) do not usually eat their hosts directly. Adult parasitoids lay their eggs in, on, or near their host insect. When the eggs hatch, the immature parasitoids use the host as food. Many parasitoids are very small wasps and are not easily noticed. Tachinid flies are another group of parasitoids. They look like large houseflies and deposit their white, oval eggs on the backs of caterpillars and other pests. The eggs hatch, enter the host, and kill it. Parasitoids often require a source of food in addition to their host insect, such as nectar or pollen. *Trichogramma chilonis* is an egg parasitoid and an agent under biological control of lepidopteran insect pests. It is effective against bollworms of cotton. Since it attacks the egg stage, damage done by larvae is avoided.

Moth Egg Parasite (*Trichogramma wasp*) is a tiny parasitic wasp and is an effective biological control agent because it kills its host before a plant can be damaged. These are extremely tiny mini-wasps used for the prevention of caterpillar and moth outbreaks by reducing the number of viable moth and butterfly eggs. It uses smell to determine the suitability of a host and deposition of its eggs. The parasitic wasp inserts its eggs inside the eggs of these pests, killing them before they enter the plant-consuming larval stage. Harmful insects it predates include armyworm, bagworm, European corn borer, peach borer, squash borer, cankerworm, alfalfa caterpillar, cutworm, corn earworm, wax moth, tomato hornworm, cabbage looper and codling moth (Ndakidemi *et al*. 2016) [18].

Biopesticide Regulation and Legislation

In the United States, Biopesticides are regulated by the same laws and regulations as traditional chemical pesticides. All Biopesticide product registrants must submit data to the Biopesticides and Pollution Prevention Division (BPPD) of the Office of Pesticide Programs (OPP) regarding the composition, toxicity, degradation and other characteristics of the product. This information is reviewed to ensure that a product will not adversely affect human health or the environment. France, Denmark, and Sweden already have aggressively reduced overall agricultural chemical use by more than 30%. Overall the number of conventional pesticides approved for agricultural use in the EU has been reduced from an all-time high of about 1,000 to a current list of 300 (Davidson *et al*., 2011) [3].

Table 1: Biopesticides Registered under Insecticides Act, 1968

S. No	Name of the Biopesticide
1.	*Bacillus thuringiensis var. kurstaki*
2.	*Bacillus thuringiensis var. galleriae*
3.	*Bacillus thuringiensis var. dendrolimus*
4.	*Trichoderma viride*
5.	*Trichoderma harzianum*
6.	Neem based pesticides
7.	Limonene
8.	Pyrethrum / Pyrethrins
9.	Rotenone
10.	Ryania

(Sharma and Malik, 2012; Gupta and Dikshit, 2010) [24, 7]

Benefits of Biopesticides

Biopesticides are manufactured from naturally occurring raw materials in an environmentally responsible and sustainable manner.

- Biopesticides are biodegradable. They decompose quickly and do not negatively impact surface water and groundwater.
- They are non-toxic to non-target organisms, including beneficial insects and wildlife.
- They improve crop quality and yield by preventing pest damage and promoting physiological benefits in plants, including increased fruit size and enhanced color.
- Manage pest resistance and extend the life of valuable traditional pesticides. (Matthews *et al*., 2014) [16]

Disadvantage of Biopesticides

- Biopesticides show high specificity, which may require an exact identification of the pest; although this can also be an advantage in that the Biopesticide is less likely to harm species other than the target.
- Biopesticides show slow speed of action thus making them unsuitable if a pest outbreak is an immediate threat to a crop.
- Biopesticides have variable efficacy due to the influences of various biotic and abiotic factors (since some Biopesticides are living organisms, which bring about pest control by multiplying within or nearby the target pest). (Tome *et al*., 2015) [25]

Future of Biopesticides

The global Biopesticide market is anticipated to raise in the coming years due to high demand for ecofriendly agricultural treatment products. Governments of various regions are implementing rules to adopt ecofriendly products for agriculture. Government agencies are also engaging in promotional activities to promote the same. The rise in trend for organic food is also leading to the rise of global Biopesticide market. The rise in awareness among urban consumers regarding the ill effects of chemically grown raw foods is one of the major factors for the rise in demand of the market. Consumers are willing to pay extra for organically produced products. The rise in growth of bio-control seed treatment solutions is fueling the market for Biopesticide. Rising cost of chemical pesticides and fertilizers are also boosting the adoption of Biopesticides in the market. The shift to sustainable methods to improve the crop yield in various parts of the world is leading to rise of global Biopesticide market. The rise in population has led to rise in food demand across the globe thus, driving the market for Biopesticides. Preference of ecofriendly pest management method over the conventional method is also another factor for the rise in demand. Biopesticide offers a variety of services such as increased efficacy of action, sustainable protection of crops, and targeted activity on pest population (Kumar and Singh, 2015) [13].

Conclusion

Biopesticides have been associated with biological control of several types of pest species. These are a form of pesticide based on microorganism or natural products. Biopesticides are an important tool for managing the increasing concern over pesticide residues in food and problem of pest resistance against chemical pesticides. Therefore, adoption of Biopesticides for crop protection is increasing in demand so as to discourage chemical pesticides that harm ecology and human and animal health. While, Biopesticides have been around for more than 50 years but the market has experienced its more significant period of growth over the past 5 years in terms of sales and user acceptance.

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