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Review Article

BIO-PESTICIDES: A VIABLE TOOL FOR ORGANIC FARMING

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Abstract- Biopesticides are effective, eco-friendly, biodegradable and do not leave any harmful residue on environment. Various types of bacterial, fungal and virus are widely used as biopesticides. Biopesticidesare categorized into three most important classes namely, microbial pesticides, biochemical pesticides and plant-incorporated protectants. In this review, use, mode of action and application of biofungicides, bacterial pesticides, viral pesticides, botanicals, pheromones, predators and parasitoids are discussed in details.

Keywords- *Biopesticides, Microbial pesticides, Botanicals*

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Introduction

Agriculture is one of the most important sectors for livelihood and nutritional security in India. Now a day's two-thirds global population basically depends upon agriculture but production of agricultural crops is continuously getting vulnerable due to attack of pests. A variety of pest such as insects, bacteria, fungi, nematodes, virus etc destroy agriculture crops. Chemical pesticides are used to control pest populations that harm the agricultural crops. Chemical pesticides are used widely in agriculture to protect the plants from destruction caused by insects, mites and weeds *etc*., but may harmful to native microorganisms and excessive use of chemical pesticides has cause various types of environmental problems [1]. Biopesticides replaced chemical pesticides. Biopesticides are effective, eco-friendly, biodegradable and do not leave any harmful residue on environment and therefore, it is used widely. In current years, production of chemical pesticides decreased by 2% per year whereas production of biopesticides increased at the annual rate of 20% [2].

Concept of Biopesticides

The biopesticide is used to protect agricultural crops from insects, fungal, bacterial and viral diseases *etc*. Plants and microorganisms are the major sources of biopesticides due to the high components of bioactive compounds and antimicrobial agents [3]. The active compounds in plants include phenols, quinones, alkaloids, steroids, terpenes, alcohols and saponins [4]. Bio-pesticide does not show any harmful effect on our ecosystem. Biopesticides is eco-friendly pest control pesticides. Biopesticides contain microbial pesticides derived from micro-organisms, biochemicals derived from natural sources and genetic modified plants or transgenic plants to express genes responsible for insecticidal toxins. Biopesticides and their by-products are widely used for the control of varieties of pests [5]. Widely used biopesticides are living organisms which are highly pathogenic for the target species only. Various types of bacterial, fungal and virus are widely used as biopesticides. Many bacterial species such as *Bacillus thuringiensis, Bacillus popilliae* and *Pseudomonas fluorescens etc*, fungus species such as *Beauveria bassiana, Verticillium lecanii* and *Paecilomyces fumosoroseus etc* and viruses such as *Lymantria dispar* and *Neodiprion sertifer etc* have capacity to protect the crops from various diseases that caused by pests.

Advantages of Biopesticides [6]

- Biopesticides are mainly designed to control on target species only and non- toxic to beneficial insects.
- Biopesticides are eco-friendly biodegradable. They decompose rapidly into small residues and do not show any negatively impact onground water and surface water.
- Biopesticides are effective in elimination of various environment pollutions with minute quantities.
- Biopesticides have low-residue, high performance and less poisonous side effects.
- Difficult for insects to develop resistance.
- Biopesticides are usually inherently less toxic as compared to chemical pesticides and ideal for integrated pest management.

Pesticides registered under insecticide Act, 1968 [7]

- *Bacillus thuringiensis* var. israelensis
- *Bacillus thuringiensis* var. kurstaki
- *Bacillus thuringiensis* var. galleriae
- *Bacillus sphaericus*
- *Trichoderma viride*
- *Trichoderma harzianum*
- *Pseudomonas fluoresens*
- *Beauveria bassiana*
- NPV of *Helicoverpa armigera*
- NPV of *Spodoptera litura*
- Neem based pesticides
- Cymbopogan

Some success stories about utilization of biopesticides and bio-control agents in Indian agriculture [8]:

- Control of diamondback moths by *Bacillus thuringiensis*,
- Management of mealy bugs and hoppers in mango and pod borer of coffee by Beauveria
- Control of *Helicoverpa* on cotton, pigeon pea, and tomato by *Bacillus thuringiensis*,
- Management of white fly in cotton with neem products,
- Control of *Helicoverpa* on gram by NVP
- Control of sugarcane borers by *Trichogramma*
- Control of rots and wilts in various crops by *Trichoderma* based products
- Categories of biopesticides and their characteristics feature

Biopesticides are categorized into three most important classes are given below:

1. Microbial pesticides
2. Biochemical pesticides
3. Plant-incorporated protectants

Microbial pesticides

Microbial pesticides consist of microorganisms such as bacterium, fungus, virus or protozoan. These microorganisms used as the active ingredient. Microbial pesticides have showed more toxicity as compared chemical pesticides [9]. Microbial biopesticides are living organisms, which are mainly pathogenic and widely used for the control of pests. Microbial pesticides are derived from naturally occurring or genetically altered bacteria, fungi, viruses and algae. They suppress pests through numerous modes of action such as producing poisonous substances specific to the target pest, regulating establishment of new microorganisms by competition and also causing diseases. Example of microbial pesticides such as biofungicides e.g., *Trichoderma*, bioherbicides *e.g.*, Phytophthora and bioinsecticides e.g., *B. thuringiensis* (Bt) [7]. Microbial pesticides are categorized into three classes such as bacterial biopesticides, biofungicides and viral pesticides given below:

Bacterial biopesticides

Bacterial biopesticides are the very common form of microbial pesticides. Bacterial based biopesticides have been used to control several plant diseases. Both spore forming and non- spore forming bacteria are used for the control of insects and diseases. They are normally used as insecticides. Bacteria interrupt the digestive system of insect by producing endotoxins which are specific to the specific insect. The mostly used bacterium is *Bacillus thuringiensis* commonly referred to as Bt. B. thuringiensis has shown their harmful effect against different insect pests in forestry, agriculture [6]. Around 40,000 species of *Bacillus thuringiensis* are used for the control of Ledopteran or Dipteran pests.At the time of spore formation Bt produces Bt -endotoxin protein that binds to cellular lining of the insect digestive tract and finally stop feeding and die. All over the world presently, several Bt strains are registered as biopesticides. Some strains of *B. subtilis* and *Pseudomonas aureofaciens* are used to control damping off and soft rots disease causing pathogens. *Agrobacterium* radio bacter are also used to control pests such as *Agrobacterium tumefaciens* (causal agent of crown gall disease). More than one hundred Bt based bioinsecticides have been formed and used against dipteran, lepidopteran and coleopteran larvae [10].

Biofungicides

The fungi cause many types of diseases on several important crops, resulting in severe plant yield losses. Fungal biopesticides effective against a number of insects as well as plant diseases. Entomopathogenic fungi have potential as mycoinsecticide agents against diverse insect pests in agriculture [11]. Generally, fungi attack hosts by entering through the cuticle, penetrating hemolymph, producing toxins and develop by depleting nutrients present in the haemocoel for exclusion of responses of insect immunity. Entomopthogenic fungi can be useful in the form of conidia or mycelium which produces spores after application. Entomopthogenic fungi can be applied as alternative insecticide or combination of insecticide and fungal entomopathogens for management of insecticidal resistance. Several biofungicidal products excite plant defence systems that can make plants more resistant to a variety stresses such as biotic and abiotic stresses [12]. *Trichoderma* spp. and *Beauveria bassiana* both are used as fungal bio-pesticides mainly applied in the nursery, field crop, ornamental and vegetable crops. *Trichoderma* used as a fungicide against soil borne diseases like root rot and therefore, it is widely used on some crops such as black gram, green gram, groundnut and chickpea because they susceptible to root rot. *Trichoderma* is a fungicide effective against several foliar and soil-borne plant pathogens such as *Rhizoctonia, Sclerotium, Fusarium, Pythium, Ceratobasidium, Macrophomina and Phytophthora* spp [13]. *Beauveria bassiana* is used against various plant pests such as aphids, thrips, whitefly and Q-Biotype Whitefly.

Viral pesticides

A bacteriophage is a virus that infects bacterial cell walls. It is used as a pesticide. They are helpful for the control the lepidopterous pests of vegetables, cotton and rice. When ingested by the host insect, infectious virus particles are liberated internally and become active. Once in the larval gut, the virus's protein overcoat quickly disintegrates, and the viral DNA proceeds to infect digestive cells. Within a few days, the host larvae are unable to digest food and so weaken and die . In 1975, Elcar™ (first viral insecticide) was proposed, by Sandoz Inc. Elcar™ was prepared by *Heliothis zea* NPV. HzSNPVwork not only against cotton bollworm, but also the pests of tomato, maize, beans, soybean and sorghum. In India, HaNPV based biopesticide is used [12]. In soybean, a well-known success of applying baculovirus, namely *Anticarsia gemmatalis nucleopolyhedro* (AgMNPV) virus as a biopesticide is reported to control velvet been caterpillar. Caterpillars of moths belonging to *Spodoptera* genus are of primary concern for agricultural production in many countries of the world. Two commercial preparations based on *Spodoptera* NPV are SPOD-X™ containing *Spodoptera* exigua NPV to control insects on vegetable crops and Spodopterin™ containing *Spodoptera* littolaris NPV which is used to protect cotton, corn and tomatoes.

Biochemical pesticides

Biochemical pesticides protect the environment from pesticidal pollution. Biochemical pesticides are naturally occurring substances and are used for the control of pests. It is eco-friendly, biodegradable and specific for target organisms. Many plants have developed biochemical mechanisms to protect themselves from various insect, bacterial and fungal attacks. Secondary metabolites such as flavanoids, phenols, alkaloids, terpenes, suberins and carotenoids etc. are also involved in developing plant immune system and defend them against both invertebrate pests and microbial pathogens [14]. The plant extracts as well as mineral oils have several benefits to natural enemies and other non-target species. Various plant grows the extracts provide help for abiotic stress such as drought, salinity and heat. A plant extract from the giant knotweed *Reynoutria sachalinensis* has control powdery mildew disease caused by *Oidium neolycopersiciin* tomato powdery mildew disease caused by *Leveillula taurica* in onion. The oils derived from several plants are toxic to diverse insect pests such as *Artemisia judaica* showed antifeedant action against *Spodoptera littoralis* (African cotton leafworm), chinensis *Zingiber officinale* control *D. melanogaster* and *Nigella sativa* control Callosobruchus [15].

Plant products

Use of botanicals is one of the important means to be used in protection of crop produce and the environment from pesticidal pollution, which is a global problem. Some plant products registered as bio-pesticides [16].

Peptidomimetics

Peptides have been pursued as valuable tools in drug discovery and development, and could be applied in insecticide design. Theoretically, using a non-peptide organic scaffold, the peptide residues critical for binding to the target ('insectophore') can be grafted onto a backbone structure to produce a peptidomimetic.

Table-1 *Predators used in management of crop pests*

Predators	Target pests	Hosts
Phytoseiulus spp.	*Tetranychus urticae, Tetranychus evansi*	*Phaseolus vulgaris, Solanum lycopersicon, Fragaria ananassa*
Neoseiulus spp.	*Tetranychus urticae, Oligonychus perseae*	*Capsicum annuum; Persea americana*
Amblyseius swirskii	*Scirtothrips dorsalis*	*Capsicum sp.*
Aphidius colemani	*Aphis gossypii*	*Dendranthema grandiflora*
Diglyphus isaea	*Liriomyza huidobrensis*	*Solanum tuberosum*
Encarsia formosa	*Bemisia tabaci*	*Solanum lycopersicon*

This non-peptidic analog has the potential to be used as a lead compound in the development of novel insecticides, overcoming the bioavailability issues of peptides penetrating the insect cuticle or gut mucosa. Nevertheless, the concept has received limited validation following attempts to 'clone' the functional residues of peptide toxins that block vertebrate calcium or potassium channels. A peptidomimetic insecticide could be challenging because noncritical residues estimated in insect toxicity bioassays can be important for averting vertebrate toxicity through steric hindrance. Besides, non-critical residues may be vital for imparting insect target subtype selectivity [17].

Use of pheromone in insect pest management

Pheromones are chemicals emitted by living organisms used to send messages to individuals of the opposite sex - of the same species. When pheromones are used in combination with traps sex pheromones can be used to determine the type of insect pests in a particular crop and subsequently the requirement for the type of plant protection management to minimize crop damage. Depending upon the effectiveness of synthetic attractant and population level pheromone traps or with the 'attract' and 'kill' technique can be applied for better success. Mating disruption is successful with application of synthetic pheromone in controlling a number of insect pests in horticultural crops. Efforts to control the pink bollworm, *Pectinophora gossypiella* (Saunders), by mating disruption initiated with the sex attractant "hexalure" in the early1970's. The discovery of the pink bollworm sex pheromone during 1970's led to the first successful commercial formulation in 1978 [18]. An inhibitor-based tactic was demonstrated to suppress infestations of the southern pine beetle, *Dendroctonus frontalis*. The southern pine beetle uses a variety of semiochemicals to mediate mass attack on host pine trees. Two aggregation pheromones, frontalin and trans-verbenol, function in directing other beetles to join in the mass attack of a host tree that is required for successful colonization.

Predators and Parasitoids as Biopesticides in Agriculture

A predator usually kills and feeds on prey while parasitoids grow on or inside their hosts and finally kill them [19]. The predators include beetles (Carabidae), ladybirds(Coccinellidae), spiders, lacewings (Chrysopidae) and truebugs while parasitoids mainly consist of wasps and other hemipterans. Examples of predator organisms used in management of crop pests are given in Table 2. These natural enemies are mainly found in the environment. In order to have them in huge numbers, they are either reared under controlled conditions and released into the fields or are multiplied in open fields containing the prey. The commonest way of rearing these predators is by growing them on their preferred hosts. This is either done in screen houses or growth chambers where the host plants are first grown and then exposed to pest infestation. The predators are then introduced and they are maintained by growing on the prey. Alternatively, the predators can be grown in cylinders where they are supplied with the prey and all other necessary conditions for growth are provided. The optimum growth of predator mite, *Neoseiulus californicus*, is observed when grown on an artificial diet supplemented with eggs of *Ephestia kuehniella, Artemia franciscana* cysts and maize bran [20]. Predators can also be grown on egg masses of their prey or other suitable hosts which gives them a longer storage capacity. This has been exploited in management of mealy bugs using parasitoids [21]. The predators can also be grown on other feeds such as rice bran. Due to economic concerns, these organisms are reared on artificial media with carefully evaluated nutritional requirements. Their growth media ranges from beef and liver to crushed lepidopteran pupae which provide a combination of hormones and nutrients needed by the predators for growth. Artificial media provides as good nutrients as the host plants and reduces the cost of growing the plants. The artificial media is mostly used in laboratories and used for rearing *Trichogramma* and *Anastatus* spp. Inundative and inoculative release or applying biological control agents such as insect predators, parasitoids and insect pathogens can have a greater role to play in controlling the insect pests in an insecticide free environment. These agents can be used as curative control methods in case of sudden outbreak in the insect population. Some of the commonly used and potential biological control agents for pest management in organic crop production. List of Biological control agents for pest management in organic crop production [22].

Plant-Incorporated-Protectants (PIPs)

Plant-Incorporated-Protectants (PIPs) are pesticidal substances that plants construct from genetic material that has been added to the plant. In agricultural biotechnology, insect resistance and disease resistance transgenic plants have used for research and development. *B. thuringiensis* and Cry proteins are alternatives source of chemical pesticides for the control of insect pests. In 1996, first commercialized production of transgenic plants (Bt plants) that express insecticidal endotoxins derived *Bacillus thuringiensis*. The expression of these toxin protein control insect crop damage. In different crops plants, the insecticidal crystal proteins coding genes have been transferred. Cry proteins form transmembrane pores, which lead to osmotic celllysis. Some plants have recently produced that code Cry proteins. In North America, Maize hybrids developed that express the *Cry3Bb1* protein, which used for the control of *Diabrotica* spp. (Coleoptera), Cotton developed that express the Cry1Ac protein used for the control of *Helicoverpa zea Boddie* (Lepidoptera), potato developed that express the *Cry3A* or *Cry3C* protein used for the control of *Leptinotarsa decemlineata* Say) (Coleoptera).

Mode of action of biopesticides

The mode of action of each type of biopesticide varies such as microbial pesticide act on pathogens by antagonisms, hyperparatism, antibiosis and predation. Botanical pesticide reduces the population of pathogens, modify their cellular and structural morphology and exhibits neuro-toxicity on insects. Botanicals also repel insects, inhibit oviposition and feeding. Predators mainly kill the prey through parasitisation or injection of toxic substances which eventually kill the prey. Semio-chemicals are used to lure the target pests and they can then be managed through other means such as sterilization or death [23]. Extracts from plants belonging to Asteraceae family have been reported to inhibit hyphal growth and induce structural modifications on mycelia of plant pathogenic fungi. Asteraceae plants contain compounds such as flavonoids, coumarins alkaloids and terpenoids which could lead to the fungal toxicity. Some compounds lead to changes in the cell wall and the morphology of cellular organelles. In some instances, the bioactive compounds cause partitioning of fungal cell membranes making them permeable leading to leakage of cell contents. Plant bioactive compounds can also lead to separation of the cytoplasmic membrane which leads to damage of the intracellular components and swelling of cells leading to eventual death. Compounds such as allicin found in garlic (*Allium sativum*) bulbs lead to suffocation of the pest due to effects on receptors of neurotransmitters. Phenolics and terpenoids build hydrophobic and ionic bonds which attack a multiple of proteins in the insects leading to physiological malfunction. Compounds present in plant extracts and essential oils also interfere with receptor cells leading to malfunctioning of the nervous system and failure of coordination leading to death of the insect. Different classes of microorganisms have different modes of actions. Hyperparasitism is one of the most reported mode of action on many biocontrol agents.

The antagonist kills the pathogen or its propagules while some attack the sclerotia or the hypha of the fungal pathogen. A single pathogen could be interfered by a number of biocontrol agents. *Pasteuria penetrans* is an example of a biocontrol agent that parasitizes on root-knot nematodes of *Meloidogyne* spp. Species of genus *Trichoderma* cause a predation mode of action by producing enzymes that directly kill cell walls of the pathogens and colonize the environment therein. Some microorganisms produce compounds that kill other microorganisms, a mechanism is known as antibiosis. This is most common with bacteria belonging to species of *Pseudomonas, Agrobacterium, Bacillus, Burkholderia, Pantoea* and also reported in the fungus *Trichoderma* spp. Some microbial species such as *Bacillus cereus* produce multiple compounds that could inhibit more than two pathogens and therefore is effective in crop disease management. Other classes of microorganisms such as *Lysobacter* and *Myxobacteria* produce lytic enzymes which hydrolyze compounds causing suppression of pathogens. *Beauveria bassiana* usually inhibits chitin development in insects by conidia attaching to the body of insects. Semicochemicals such as female sex pheromones are used to lure the male insect pests which are then sterilized and eventually decreasing their effectiveness. Upon mating with the sterile male insects, the females lay unfertilized eggs thereby reducing harmful insect populations. Host location pheromones lure insects into sites with mass traps from where they may be sterilized or starved to death. Predators may feed on the prey or a particular life stage of the prey such as nymphs or larvae. The predator prey ratio is of importance in balancing the populations of the pests and also biodiversity.

Biopesticides in Sustainable Agricultural Production

Biopesticides are as effective as synthetic pesticides in management of pests in crops [24]. Natural products are also eco-friendly since they are easily biodegradable and they do not pollute the environment. For organically produced food, this makes biopesticide is suitable alternatives to synthetic pesticides. Biopesticides have very short pre-harvest intervals and are therefore safe to use on fresh fruits and vegetables [25]. They are also target specific and hence do not affect the beneficial organisms like the natural enemies. Biopesticides are effective in small quantities and their use promote sustainable pest management and hence contribute towards sustainable agriculture. Natural pesticides do not allow resistance build up among pests. They are easily found within the natural environment and some of them are used for other purposes like food and feed. Biopesticide are safe products both for the applicant and the consumer due to their low toxicity. Therefore, biopesticides can effectively be incorporated in integrated pest management (IPM) which reduces the amounts of chemical pesticides used in management of pests in crops. Most microbes produce and secrete one or more compound with antibiotic activity. Some examples of antibiotics reported to be involved in plant pathogen suppression. Some antibiotics produced by biocontrol agents [26].

Biopesticides formulations

The basis for most of the biopesticides is living organisms and their viability should be maintained during the formulation process and stored at acceptable levels. The organisms definitely revive from their dormant state in order to be active at the application time [27]. Final product is made by mixing the microbial component with different carriers and adjuvants during formulation process for better protection from environmental factors, controlled rates, improved bioactivity and storage stability. Depending on the physical states of the biopesticide formulation as dry or liquid forms, the active ingredients are prepared by addition of stabilizers, synergist, spreads, stickers, surfactants, colouring agents, anti-freezing compounds, additional nutrients, dispersants and melting agents [28]. In general, biopesticides are usually formulated as dry formulation (for direct applications) and liquid formulations. Amongst dry formulations, dustable powders, granules, seed dressings, wettable powder, water dispersible granules whereas emulsion, suspension concentrate, suspo-emulsion, oil dispersion and capsule suspension are common among wet formulations. Biopesticides are applied through seed treatment, foliar and seedling dippings.

Conclusion

The indiscriminate use of chemical pesticides has resulted in several ill effects such as social health hazards, ecological imbalances both in flora and fauna and environmental pollution through pesticide residue in the soil, water, fodder and food crops in addition to destruction of natural enemies of pests. The dynamism of soil and living organisms like predators, parasites and pathogens and the resultant ecological balance will be destroyed with long term use of chemical inputs in agriculture. To feed the future generation without degrading the resources that support crop productivity, agriculture must become economically viable and ecologically sustainable which could be achieved through organic farming. Most of the countries across the globe encourage the development and use of biopesticides.

Application of review: The use of biopesticides excludes the use of synthetic chemicals like high analysis fertilizers, chemical pesticides. It helps in reducing the input cost as well as maintenance cost of healthy soil and environment.

Review category: Organic agriculture

Abbreviations: Bt: *Bacillus thuringiensis*
AgMNPV: Anticarsia gemmatalis nucleopolyhedrovirus
PIP: Plant-Incorporated-Protectants

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