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Bio-pesticides: A Green Approach for Insect-pests and Disease Management

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Introduction:

The term "Bio-pesticides" is usually used for all biological materials and organism which can be formulated for use as a pesticide for pest management. These include microorganisms such as bacteria, fungi, virus and as well as materials of plant origin such as a neem. These so-called bio-pesticides exhibiting a variety of modes of actions. They are considered as minimal risk products safe to human and his environment.

Traditionally, chemical pesticides have been in use for pest management as these have been effective, dependable and economical. However, their indiscriminate use has resulted in several problems such as development of resistance in pests and diseases against pesticides, pest resurgence, toxic residues in food, water, air and soil, elimination of natural enemies and disruption of ecosystem and their continued use may further harm the environment. There is an urgent need for natural/organic farmers to gain more proficiency in using bio-pesticides. There are several types of bio-pesticides, including bio-insecticides, bio-fungicides, bio-nematicides, and bio-herbicides. The bio-pesticides fall into three major categories.

- **Microbial pesticides:** Microbial pesticides are the most common pest-specific, broad-spectrum bio-pesticides. These contain microorganisms such as fungi, bacteria, virus, protozoa and nematodes or their derivatives with deleterious effects on insect-pest and diseases of different crops. Microbial bio-pesticides are self-sustaining, host-specific, and environmentally safe.
- **Biochemical/Botanical pesticides:** These are naturally occurring plant materials that are used for managing the insect-pests and diseases of different crops. The most extensively used biochemical pesticide is neem oil, neem seed kernel extract, and neem extract concentrates from bark and leaves, all of which are accessible in India.

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Biochemical pesticides also include essential oils from canola, tea tree, lemongrass (*Cymbopogon citrates*), and pyrethrin from *Chrysanthemum cinerariaefolium*.

- **Plant Incorporated Protectants (PIPs):** Plants with the toxin-producing genes to fight against the pest are called plant-incorporated protectants or genetically modified crops or genetically engineered plants. These PIPs help the plants to resist bacteria, fungi or viruses.

Current status of bio-pesticides:

There are several bio-pesticides that are commercially available to farmers. According to the latest information, there were approximately 970 microbial formulations and 15 microbial species registered with the Central Insecticide Board and Registration Committee (CIBRC) in India. Bio-pesticides make up about 5% of the global crop protection market. In the fruit and vegetable sector, bio-pesticides account for more than 18% of the market. The use of bio-pesticides has been increasing, with a compound annual growth rate (CAGR) of 11% from 2018 to 2022. The global bio-pesticides market is expected to grow at a compound annual growth rate (CAGR) of 10.3% from 2024 to 2033. The importance of some commonly used bio-pesticides and recent development in bio-pesticide research as follows:

A. Microbial pesticides:

Fungal Pathogens:

Mycofungicide:

- ***Trichoderma* spp.:** *Trichoderma* is one of the most important agriculture soil microbe. *Trichoderma* spp. is free-living that are present in soil and root ecosystems and other natural habitats especially those containing high organic matter. Currently, most recognized and widely used *Trichoderma* spp. are *Trichoderma viride, T. harzianum and T. virens* as bio-fungicide. Against fungal pathogens, *Trichoderma* spp. rely on three major mechanisms, viz. mycoparasitism/hyperparasitism, antibiosis and substrate competition. *Trichoderma* spp. is recommended for seed treatment, soil application even foliar spraying for management of seed and soil borne diseases such as damping off, root rot, collar rot, stem rot, wilt, grey mould, sheath blight, etc. of different crops like cotton, blackgram, green gram, chickpea, chilli, groundnut etc. caused by *Pythium, Rhizoctonia, Sclerotinia, Sclerotium, Fusarium, Macrophomina, Botrytis* etc. This biofungicide marketed as talc/liquid-based product in the market. *Trichoderma* spp.

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generally used to control the diseases as seed treatment @ 8–10-gram *Trichoderma* spp. (powder formulation $2x10^6$ cfu/g) with 50 ml of water (bigger seeds) while small seeds at the rate of 6-8 gram for the treatment of one kg seed before sowing. Apply 5-10 ml *Trichoderma* spp. (liquid formulation) per litre of cow dung slurry for treatment of one kg seed before sowing particularly for cereals, pulses and oilseeds. Shade dries the seeds for 20-30 minutes before sowing is essential. Seed treatment is highly effective against seed and soil borne diseases. Seed biopriming is treatment of seed with *Trichoderma* formulations (@ 5-10 gram/kg seed) and incubating under moist and warm conditions until just prior to radicle emergence. Seed biopriming is beneficial for tomato, brinjal, chickpea, soybean etc. crops. For seed material treatment, Apply at the rate of 8-10gram *Trichoderma* powder with one litre of water (30 minutes) for the treatment of seed material like sugarcane setts, banana suckers, turmeric, ginger rhizomes and potato tubers before sowing. Shade dries the seeds for 20-30 minutes before sowing is essential.

- ***Aspergillus niger:*** It is a powerful antagonist of various pathogenic fungi and is gaining popularity as a biological agent. Studies have shown that an excellent strain of *A. niger* strain AN 27 prevented spore germination and caused aberration and lysis of chlamydospores and sclerotia of numerous soil-borne plant pathogenic fungi. It can be manage several devastating soil-borne diseases like wilt, root rot, damping off, etc. caused by *Fusarium, Pythium, Macrophomina, Sclerotinia* etc. in diverse group of crop plants, ornamental, fodder and fibre crops. Commercial formulation of *A. niger* AN 27 is used for seed dressing @ of 8-10 gram/kg seeds. It has very extended shelf life of two years.
- ***Ampelomyces quisqualis:*** It is a naturally occurring hyperparasite fungus that is being used as a biofungicide against mildews and others in okra, eggplant, chilli, tomato, grapevines, potato, cucumber, and so on. It infects and produces pycnidia within powdery mildew hyphae, conidiophores, and clestothecia. The mycoparasite penetrates the walls of hyphae, conidiophores, and juvenile cleistothecia but may not infect mature cleistothecia. It spreads through the mildew colony's hyphae in 7-10 days, eventually destroying it. The commercial formulation is sold as a talc-based WP product containing approximately 1 x 10^8 cfu's/gram spores and mycelial fragments of *A.*

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quisqualis. As a preventative approach, a foliar spray of 5 g/litre of water might be used.

Mycoinsecticide:

- ***Beauveria bassiana:*** It is an entomopathogenic fungus used as a bio-pesticide in crop pest management. It lives in the soil saprophytically and frequently produces large epizootics that kill out insect populations on crops. These parasites enter the host insect body by food or contact with the host cuticle, where they multiply. It creates poisons such as beauvericin, bassianocide, and others inside the host body, causing paralysis and eventually killing the insects within four or five days. These entomopathogenic fungi are used to manage caterpillars such as the yellow stem borer and leaf folder of rice, the white grub of groundnut, the coconut rhinoceros beetle, sugarcane pyrilla, caterpillars of pulses, tomato, and cotton, diamond back moth, leaf eating caterpillars of tobacco and sunflower, and others in an environmentally friendly manner. This bio-pesticide is marketed as a talc based WP product containing spores and mycelial fragments @ 1 x 10^8 cfu's/gram of *B. bassiana*. Soil application of this bio-pesticide generally recommended @ 1-2 kg per acre (powder formulation) with 80-100 kg well decomposed farm yard manure. This mixture can be applied in furrow/pit/pot and at the time of transplanting/sowing for termite, white grub and other soil pest management. It should be repeated after 2–3-week interval. It is used as foliar spray @ 1.0-1.5 kg of *B. bassiana* culture in 200 liters of water with sticker in one acre area for management of sucking pests, bug and beetles etc. Maintain optimum soil moisture while applying. Repeat application at 2–3-week interval as and when required.
- ***Metarrhizium anisopliae:*** It is a fungal insecticide for use against a wide range of insects including soil insects, caterpillars, sucking pests and locusts. This pathogenic fungus is mostly used to manage the coconut rhinoceros beetle, groundnut cut worm, rice brown plant hopper, diamond back moth, and sugarcane early shoot borer, top shoot borer, and internode borer. This bio-pesticide is marketed as a talc-based WP product containing spores and mycelial fragments @ 1 x 10^8 cfu's/gram of *M. anisopliae*. The spores of the fungus come in contact with the cuticle (skin) of susceptible insects, they germinate and grow directly through the cuticle to the inner body (haemolymph) of their host. The fungus proliferates throughout the insect's body,

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and produce toxins, viz. destruxins A and B which stop the physiological process of insect in 7-10 days depending on conditions, especially temperature, humidity and doses. The fungus infects the insect with contact and as such do not need to be consumed by their host to caused infection. Applications are same as *B. bassiana.*

- ***Nomuraea rileyi:*** It is also an entomopathogenic fungus used as a bio-pesticide against *Sopdoptera litura, Helicoverpa armigera* of groungnut, sorghum and chickpea etc. *Nomuraea rileyi* is a dimorphic hyphomycete that may induce epizootic death in various insects. *N. rileyi's* host specificity and environmentally favourable characteristics support its application in insect pest management. This biological control is effective against a variety of insect hosts, including *Trichoplusia* sp., *Heliothis zea, Bombyx mori, Plathypena scabra*, and others. Mode of action of the fungus, commercial formulation and application are same as *M. anisopliae*.
- ***Paecilomyces fumosoroseus:*** It is a major bio-control agent against whiteflies that causes "yellow muscardine." The ability of this fungus to grow extensively over the leaf surface under humid conditions is a characteristic that certainly enhances its ability to spread rapidly through whitefly populations. These fungi cover the whiteflies body with mycelial threads and stick them to the underside of the leaves. The nymphs show a “feathery” aspect and are surrounded by mycelia and conidia. This fungus is used to manage yellow and red mites, whiteflies, and other insects in both field and greenhouse environments. Commercial formulation and application are same as *M. anisopliae*.
- ***Verticillium lecanii:*** It is a naturally occurring entomopathogenic fungus which can be used as a bio-pesticide. The fungus *V. lecanii* is widely spread and can produce massive outbreaks in tropical and subtropical climates, as well as in warm and humid conditions. *Verticillium lecanii* is most effective to manage the whitefly, thrips, mealy bug and several aphid species of vegetables and ornamentals etc. Mode of action of the fungus, commercial formulation and application are same as *M. anisopliae*.

Myconematicide:

- ***Paecilomyces lilacinus:*** It works as a biological nematicide. This fungus's spore infects and kills eggs, juveniles, and young adults of most nematode species, including root knots, cysts, burrowing nematodes of vegetables, bananas, spices etc. When come in contact with stages of nematode, they germinate and grow and proliferate throughout

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the nematode, eventually paralyses and kill them. It is sold as a talc-based WP product containing spores and mycelial fragments of *P. lilacinus* a common saprophytic fungus with a cosmopolitan distribution. It can be applied to the soil @ 3 kg/ha. However, minimum 15 days waiting is necessary between *P. lilacinus* and fungicide treatment.

Bacterial Pathogens:

Bacterial bio-insecticide:

- ***Bacillus thuringiensis* (Bt):** *Bacillus thuringiensis* var. *kurstaki* is the most commonly used and commercially most successful bio-pesticide. It is primarily a pathogen of most damaging second instar larvae of lepidopteran pests such as American bollworm in cotton, caster semi looper, tobacco caterpillar, diamond black moth on cruciferous vegetables, rice stem borer and *Heliothis armigera* on various crops. Bt is an aerobic spore-forming bacterium off Coccobacilli group and its insecticidal property is due to crystals of insecticidal proteins produced during sporulation. When ingested by larvae Bt releases toxins (delta-endotoxin) which damage the midgut of the pest causing septicaemia and death within 2 to 3 days. It is also safe to humans. General recommended dose of spraying is 1-1.5 ml/g per litre of water. It acts very well during afternoon hours and in cold climate. Several strains of Bt have been isolated and are now mass produced and sold as pest control agents. Each strain has different host specificity.
- ***Bacillus popilliae:*** It cause milky disease (causing turbidity of body fluid) in the larvae of chafer grubs and kill. The production of parasporal inclusions within the sporangial cells has been observed in *B. popillae*, even if they are not directly responsible for the insecticidal action. After the spores are ingested by the host, they germinate in the midgut (Mampallil *et al.*, 2017). Application are same as *B. thuringiensis.*

Bacterial bio-fungicide:

- ***Pseudomonas fluorescens:*** This bio-fungicide controls the pathogen by substrate competition for nutrient available in the soil and phyllosphere. It can be used against *Pythium* spp., *Fusarium* spp., *Rhizoctonia solani*, *Sclerotium rolfsii*, *Botrytis cinerea* etc. of different agriculture and horticultural crops. It is commercially available as a talc-based WP product which is widely used as a seed treatment at the rate of 4 gram per kg seed and soil application @ 2 to 3 kg per hectare along with any organic manure

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before sowing and against the seed borne and soil borne diseases and also as foliar spray @ 10 gram per litre of water for rice blast, sheath blight, sheath rot brown spot and glume discussion management. It is also comfortable with fungicides and *Trichoderma viride*. A commercial formulation of *Trichoderma viride* + *Pseudomonas fluorescence* is also available in the market for soil application to manage soil borne pathogen causing seedling diseases.

- ***Bacillus subtilis:*** It is an excellent antagonist for management of soil borne diseases of cotton. Application is same as *Pseudomonas fluorescence.*

Viral Pathogens

Insect viruses belonging to the family Baculoviruses (BV) can infect and destroy a number important crop pests and are also frequently utilized as viral bio-pesticides (viral insecticide). They are effective against the lepidoptoran pests of cotton, rice and vegetables. The NPV and GV are most popular in recent years and farmers are using them as bio-pesticide in several crops as baculoviruses have no deleterious effect on useful insects, pollinators and non-target organism and human beings. NPV is used for management of Helicoverpa (HaNPV) and Spodoptera (SiNPV). GV is used against *Cydia pomonella* on apple, *Pthorimaea operculella* on potato and *Plutella xylostella* on cabbage. General recommended odse of spraying of NPV and BV is @ 1 ml/litre of water (i.e. 250 LE/ha; LE= Larval equivalent; 1 LE= 6 x 10^9 PIB; PIB= Polyhedral inclusion bodies). NPV and GV act as a true stomach poison. The effective lethal concentration (LC_{50}) of NPV is 1 x 10^9 /mL for *H. armigera* larvae. For gram, pigeon pea and cotton HNPV at 250–300 LE, 500 LE and 250 LE/ha should be used.

Protozoa:

Protozoans are sometimes called microsporidians. Microsporidia are ubiquitous obligate intracellular parasites that can attack lepidopteran and orthopteran insects and hence can be utilized as part of an integrated pest control program, such as *Nosema* sp. and *Vairimorpha* sp. One notable exception is *Nosema locustae,* a microsporidian that has been mass-produced and marketed for management of grasshoppers.

Entomopathogenic Nematodes (EPN):

The entomopathogenic nematodes (EPNs) have the ability to cause disease in insects by suppressing the immune system of insects. *Steinernema carpocapsae, Heterorhabditis bacteriophora*, *H. indica* products are registered and sold in India. It controls rice moth, gram

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pod borer, white grub, tobacco caterpillar, diamond black moth, leaf minor, mole cricket, corn root worm and citrus root weevil etc. EPNs usually must be applied to soil at minimum rates of 2.5 x 10^9 IJs/ha (=25/cm^2) or higher. Before application of EPN, irrigate the field before 2-3 days to maintain the soil moisture or if required moisture level is already present in the field then EPN can be applied. While preparing the field, 2-5 kg/acre EPN culture (powder formulation) is added in 20-50 kg well decomposed farm yard manure (FYM) or vermin-compost/cocopit/sand. 5-25 gram EPN is required for plantation and fruit crops/plant. Spray of 1000 IJs per plant (equivalent to 125 million IJs/ha) or @ 1x10^6 IJs/ml or 3x10^9 IJs/ha as a prophylactic control measure. For stem borer/Pseudostem weevil/Banana stem weevil (*Odoiporous longicollis*) management, the holes along with frass material or jelly like exudations are observed on pseudostem, inject 20 ml of active infective juveniles (IJs) of EPN @1000 IJs/ml in to the holes as curative measure.

B. Biochemical/Botanical pesticides:

Plant-derived compounds, sometimes known as phytochemicals or herbal insecticides. Phytochemicals are found in a variety of plant parts, including fruits, vegetables, grains, legumes, nuts, seeds, and bark. It has many bioactive chemicals with antiparasitic, bactericidal, fungicidal, viricidal, and insecticidal effects, making it a possible alternative to inorganic pesticides. Terpenes contain phyto-volatiles and glycosides, whereas sterols contain phenolic components such as phenolic acids, lignin, tannins, and alkaloids. Secondary metabolites are essential components of the plant's insect defence system. It functions as a toxin, insect growth regulator, repellent, and antifeedant (Mossa, 2016). Currently, only a few phytochemicals are employed as bio-pesticides, with the majority of them being neem-based. These are primarily 3% neem oil or 5% neem seed kernel extract concentrations that can be sprayed at a rate of 25 kg/ha to control important agricultural pests (Rajamani and Negi, 2021).

Herbal pesticides function by absorption through the insect cuticle, inhalation, or ingestion, affecting the insects' physiology, metabolic pathway, or neurological system. It interferes with insect respiration by obstructing spiracles, causing asphyxia. Monoterpenes included in essential oils operate as neurotoxins, inhibiting the acetylcholinesterase enzyme involved in nerve impulse transmission in insects, resulting in paralysis and death.

C. Plant Incorporated Protectants (PIPs):

Plants having toxin-producing genes to combat pests are known as plant-incorporated protectants, genetically modified, or genetically engineered plants. These PIPs aid plants in

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resisting bacteria, viruses, and fungi. Pest-resistant crops are those that use PIPs to control a specific pest. Some of the examples of PIPs are soybeans, brinjal, cotton, corn, potatoes, and tomatoes. Transgenic plants are created by transferring the target gene via *Agrobacterium*-mediated transfer, gene gun or ballistic techniques. These approaches were employed on wheat, maize, rice, and corn (Rajamani and Negi, 2021).

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