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Biopesticides as an Opportunistic Control Measures Against Insect Pests - A Review

Summira Rafiq[*1], Shafiya Rashid[*2], M. A. Mantoo[*1], T. H. Askary[*1], Qurat-ul-ain binte Syed[*3], Nusrat ul Islam[*4]

[*1]Division of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology, FOA Wadura, Sopore

[*2]Division of Entomology, Sher-e-Kashmir University of Agricultural Sciences and Technology, Chatha, Jammu

[*3]Division of Agroforestry, Sher-e-Kashmir University of Agricultural Sciences and Technology, Chatha, Jammu

[*4]Division of Plant Breeding and Genetics, Sher-e-Kashmir University of Agricultural Sciences and Technology, FOA Wadura, Sopore

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Abstract

Despite the risks associated with using synthetic chemicals to manage pests, they are nonetheless widely employed in all countries across the world. Increased social pressure to gradually replace them with alternatives that are safe for humans and non-target organisms has led to increased development of compounds based on models of naturally occurring active ingredients of biological origin, known as "biopesticides," which have a variety of biological activities. Microbial pesticides, biochemicals produced from microorganisms, phytochemicals and other natural sources and methods involving the genetic alteration of plants to express genes encoding insecticidal toxins are all examples of biopesticides. Biopesticide application for pest control is still a developing field in pest management. This paper reviewed the current state of knowledge on the potential use of biopesticides for pest control all around world, highlighting the concept of biopesticides, their categories, use in pest management, formulations, application methods at various stages of advancement in both delivery and efficiency with key examples of successful commercial control of pests for agricultural crops and finally empherical information on mechanisms.

Keywords: Biopesticides, Biological Pest Management, Formulations, Biochemicals.

Introduction

Numerous pests, such as plant pathogens, (fungi, bacteria, nematodes, and others) insects, and weeds have afflicted agriculture, resulting in a severe fall in output (Saima and Jogen, 2011). Pest-related crop losses, combined with other issues such as bad weather, farmers limited access to technical know-how and poor soil conditions, jeopardise food security. Pests are thought to be responsible for a 40% drop in global agricultural productivity (Oerke *et al.*, 1994). It is critical to manage these pests in order to promote food security and satisfy the needs of an ever-increasing human population and this must be done in such a way that no harm is done to human health, public goods or the environment that farming delivers (Bastianns *et al.*, 2008). Crop protection against pests has relied solely on chemical pesticides for the previous half-decade and new restrictions on chemical use as well as the evolution of resistance in insect populations has resulted in a decline in their use. Aside from that the usage of synthetic pesticides is becoming increasingly problematic due to a variety of concerns (Management failure as a result of excessive prophylactic use of pesticides through pest resurgence and the development of heritable resistance (Van Emden *et al*., 2004). Herbicide-resistant weeds are estimated to number over 200 species, while over 500 species of arthropods have gained resistance to various insecticides (Heap, 2012). Biopesticides serve a vital part in agriculture's long-term viability (Prasad *et al*. 2014). It causes death by drastically diminishing arthropod populations before they reach an economically significant level (Betz *et al*. 2000). Biopesticides must be included in Integrated Pest Management Programs (IPM) to make them more sustainable, as they are phytotoxic, leave no residues, and are environmentally beneficial (Bhattacharyya *et al*. 2016).

Biopesticides as a concept

Bio-pesticides are non toxic agents derived from living organisms (natural enemies), their products (microbial products, phytochemicals) or by-products (semiochemicals) that can control pests (Salma and Jogen, 2011). Biopesticides are made mass produced chemicals obtained from natural sources live microorganisms and commercialised for use in pest control, according to the Organization for Economic Cooperation and Development (2009). Biopesticides, according to (Suman and Dikshit, 2010), include a wide range of microbial pesticides, biochemicals derived from microorganisms and natural sources.

BiopesticideCategories

Biopesticides are divided into four categories:

(1) Microbial pesticides

(2) Biochemical pesticides

(3) Plant-Incorporated-Protectants (PIPs)

(4) Semiochemicals

(1) Microbial Pesticides: These are pesticides that contain microorganisms such as bacteria, viruses, fungi and protozoa as active components and are used to manage plant diseases, pest insects and weeds biologically. Entomopathogenic pathogens are those that infect insects. Other animals or plants are not harmed by the bacteria that cause insect illness. *Bacillus thurengiensis*, an insect pathogenic bacterium is the most extensively employed microbe in the production of biopesticides (Bt). Most Lepidoptera, Coleoptera, and Diptera use this bacteria as a pesticide (Gill *et al*.,1992). During the spore production of *B. thuringiensis*, the bacteria create protein crystals or toxin that can cause gut cell lysis when fed by a specific or susceptible insect (Chandler *et al*., 2011). Biologically derived insecticides is a more fair description of Bt. Because their host range prohibits them from infecting vertebrates, entomopathogenic fungi have been used as biological control agents to a larger extent than entomopathogenic bacteria. Baculoviridae, Poxviridae, and Reoveridae are the three families of entomopathogenic viruses. In the subkingdom, there are approximately 1200 species. Protozoa are insects that enter their hosts through the mouth and reside in the gut, such as *Malamoeba locustae*, *Vairimorpha necatrix*, and *Nosema locustae*. Entomopathogenic nematodes are members of the Steinernematidae and Heterorhabditidae families which are closely related to the bacteria *Xenorhabdus nematophilus* and *Photorhabdus luminescens*.

***Bacillus thuringiensis* subspecies and toxin used against various pests are listed below**

Bacillus thuringiensis subspecies	Toxin class	Prototoxin size (K Da)	Target insect
Bt subsp. *Berliner*	Cry I	130–140	Lepidoptera
Bt subsp. *Kurstaki*	Cry I	130–140	Lepidoptera
Bt subsp. *Kurstaki*	Cry II	71	Lepidoptera, Diptera
Bt subsp. *Aizawai*	Cry I 135	135	Lepidoptera
Bt subsp. *Tenebrionis*	Cry III	66-73	Coleoptera
Bt subsp. *Israelensis*	Cry IV	68	Diptera

***Bacillus thuringiensis* Mechanism of Action**

During the spore generation process, *B. thuringiensis* creates protein crystals, which are responsible for the lysis of gastrointestinal cells in vulnerable insects (Chandler *et al*. 2011). *B. thuringiensis* is a bacterium that manufactures crystalline proteins (cry and cyt).

When the larva consumes cry protein, delta-endotoxins are activated in the larvae gut, which has an alkaline pH. (9.0 to 11.0). The proteins bind to the gut receptor site, causing holes to form in the cells of the midgut (Kumar 2012). Bt toxin paralyses the midgut, causing the discharge of gut contents into the insect's haemocoel, disturbing the pH balance, and eventually killing the pest (Betz *et al*. 2000; Zhu *et al.* 2000; Darboux *et al.* 2001).

Figure 1: Bacterial pesticide mode of action

Cyt toxins, unlike Cry proteins are injected directly into an insects lipid membrane. Cyt, a membrane-bound receptor for Cry toxin, synergizes or reduces tolerance to mosquitocidal-Cry proteins, according to new research. The toxins Cry and Cyt are both pore-forming (Aronson and Shai 2001; Bravo *et al*. 2007)

EPN's Mechanism of Action

Infectious third stage juveniles (0.4–1.5 mm in length) enter an insect through natural apertures such as the mouth, anus or breathing holes. Nematodes enter the body cavity of insects and release their symbiotic bacteria into the hosts intestine. The bug is killed in a week by the bacteria's toxins. It liquefies its host by feeding on the cadaver. On the host cadaver, nematodes reproduce and produce three generations of progeny. Infectious juvenile nematodes migrate away from the dead insect in search of a new host. Nematode-infected pest stages should be present 5–7 days following administration under ideal conditions. Steinernematidae killed insects turn brown or tan, while Heterorhabditidae-killed insects turn red.

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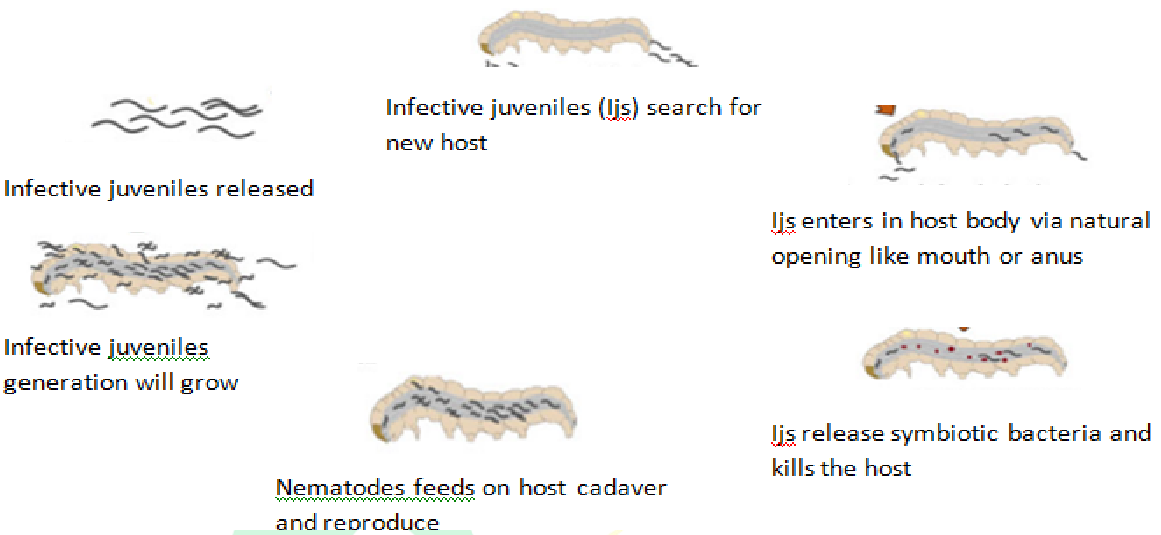

Figure 2: EPN's Mechanism of Action

(2) Biochemical Pesticides: These are non-toxic compounds such as hormones, enzymes, pheromones and natural agents that control pests. Because determining whether a natural pesticide can control a pest using a non-toxic mode of action can be challenging at times, the Environmental Protection Agency (EPA) has set up a committee to investigate if a pesticide fits the criteria for a biochemical pesticide (Salma and Jogen, 2011). Plants that produce secondary metabolites are considered biopesticides as well (Schumutterer, 1990).

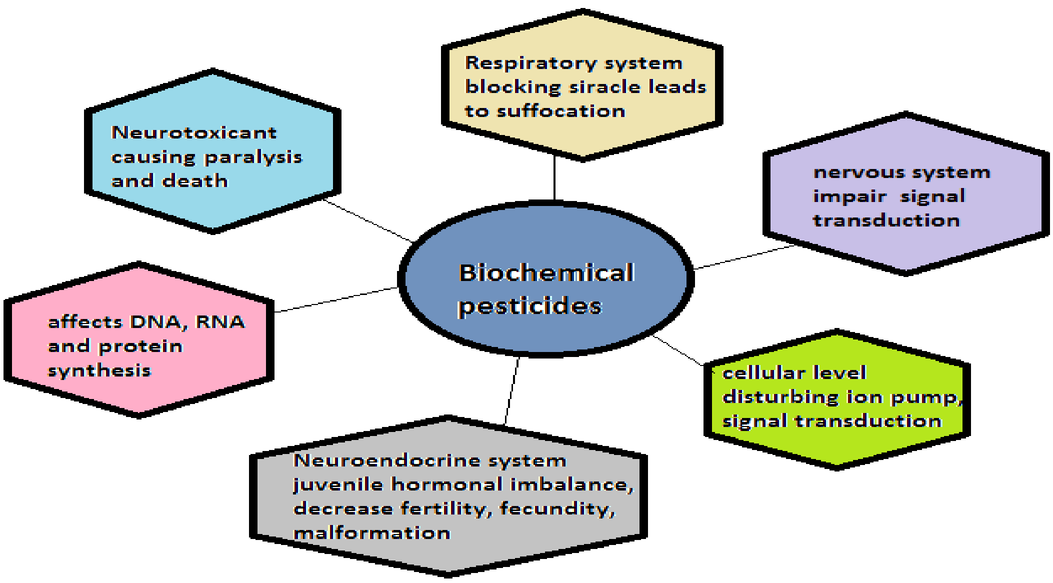

Figure 3: Biochemical insecticides mode of action

These include the following: Insect Growth Regulators, often known as IGRs, are chemical substances that affect insect growth and development.

- Chitin synthesis inhibitors, such as benzoylureas, buprofezin, and cyromazine, block the creation of chitin, a carbohydrate that is a key structural component of the insect skeleton.
- Ecdysone, juvenoids, and juvegens are examples of juvenile harmone analogues and imitators that cause sterilisation, disturb behaviour, and disrupt diapause.
- Anti-juvenile hormone drugs, such as percocenes, nullify the impact of juvenile hormone by preventing its production.
- Tebufenozide, halofenozide, methoxyfenozide, and chromafenozide are hydrazine insecticides, a newer class of insecticidal IGRs that comprises tebufenozide, halofenozide, methoxyfenozide, and chromafenozide.

(3) Plant-Incorporated-Protectants (PIP) are biopesticidal compounds produced by plants from genetic material that has been introduced or incorporated into their genetic makeup. PIPs are also known as Genetically Modified Crops or plant pesticides. Bollgaurd® cotton with Bt. Cry1Ac delta-endotoxins, which was experimentally introduced in 1995 and is resistant to tobacco budworm, cotton bollworm, and pink bollworm as well as other minor lepidopteran pests, is a good example of this. Cotton, corn, and other insect-resistant crops treated with Bt release one or more crystalline proteins that destroy the gut lining of sensitive insect pests feeding on their tissues, causing the pests to cease feeding and die (Siejel, 2001). It is safe for beneficial organisms, humans, and the environment and it has no negative effects on vertebrates (Lacey and Siegel, 2000). Since 1995, several plant pesticides have been approved for use in the United States. The effectiveness of these plant insecticides has been enhanced or augmented by the use of stacked genes in several product introductions. This means that many transgenes are injected into a single crop in order to attain various desirable traits.

(4) Semiochemicals are chemical signals produced by one organism, typically insects that elicit a behavioural shift in another individual of the same or other species. Pheromones are substances that communicate information between members of the same species, while allelochemicals are compounds that communicate information between species. Insect pheromones, which serve as a signal to communicate with others in their species for a variety of reasons and are synthesised for pest control by mating disruption, Lure-and-Kill systems, and mass trapping, are the most widely used semiochemicals for crop protection. Sex pheromones (gossyplure, disparlure, looplure, etc.), aggregation pheromones (Frontalin, ipsenol, periplanone), alarm pheromones (Terpenes, aldehydes, formic acid), and trial pheromones are all examples of pheromones (Caproic acid, hexanoic acid, heptanoic acid). Allelochemicals come in a variety of forms.

- Allomone is beneficial to the emitter but harmful to the recipient.
- Kairomones benefit the recipient but not the sender, while Synomones benefit both the sender and the receiver.
- Antimone is a type of antimone that is harmful to both the receiver and the emitter.
- Apneumone a chemical emitted by nonliving things that benefits the recipient but harms other organisms in the substance.

Formulations of Biopesticides

Biopesticides active chemicals are usually prepared in the same way as synthetic pesticides, making it most convenient for farmers to apply them with the same equipment (Slavica and Brankica, 2013). Living organisms are the basis for most biopesticides and their viability must be maintained during the formulation process and stored at acceptable levels. To be active at the time of application, the organisms must awaken from their dormant state (Boyetenko, 1998). For better protection from environmental factors, controlled rates, improved bioactivity and storage stability, the microbial component is mixed with different carriers and adjuvants during the formulation process. To ensure the most important functions of the developed biopesticides formulation, such as easy handling and application of the product, stabilisation of the microbial agent during distribution and storage, protection of the bioagent from adverse environmental conditions, and enhancement of the bioagent's activity by increasing contact and interaction with the target pest, Biopesticides are made in a variety of methods (Mollet and Grubenmann, 2001). Stabilizers, synergists, spreads, stickers, surfactants, colouring agents, anti-freezing compounds, additional nutrients, dispersants, and melting agents are added to biopesticide formulations depending on their physical states as dry or liquid forms (Brar *et al*., 2006; Knowles, 2008). Biopesticides are typically available in two forms: dry formulations (for direct application) and liquid formulations.

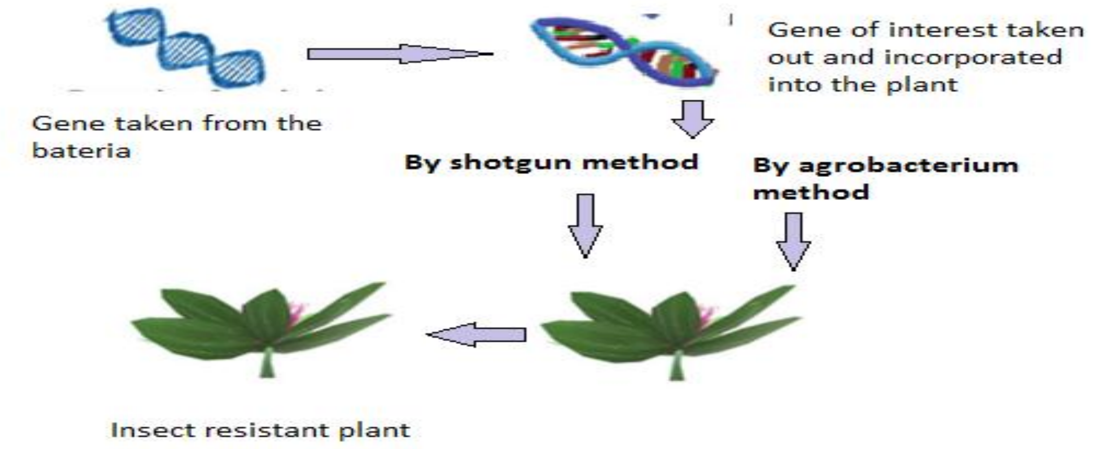

Figure 4: Shows a method for making plant-based protectants

Direct application of a Dry Formulation

- **Dustable Powders (DP):** The active ingredient concentration in dust formulations is typically 10%, and the active ingredient is produced by sorption of the active component on finely ground solid mineral powder (talc, clay, etc.) with particle sizes ranging from 50 to 100 mm. UV protectants, adhesive materials (stickers) to improve adsorption and an anti-caking agent are inert additives for dust formulations (Slavica and Brankica, 2013).
- **Granules (GR):** Granules include active substances in concentrations ranging from 2 to 20%, and the active components coat the exterior of the granule or are absorbed into the granule. Granules can be coated with resins or polymers to modulate the pace of efficacy of active substances following application. Granules are primarily used to manage soil-dwelling insects, weeds, and nematodes via root uptake. Granules with coarse particles ranging from 100 to 600 microns manufactured from kaoline, silica, starch, polymers, groundnut plant waste, dry fertilisers, and other ingredients (Slavica and Brankica, 2013; Tadros, 2006). After being exposed to soil moisture, some granules release their active components.
- **Seed Dressing (SD):** This is a type of biopesticide formulation made by combining a powdered active component carrier with an inert to help the end product attach to seed coats. Seed dressing powders are applied to seeds by tumbling them with a product

designed to stick to them, and they also contain colourants such as red pigment as a safety marker for treated seed (Woods, 2003).

- **Wettable Powders (WP):** They are dry formulations that are finely powdered and administered after being suspended in water. Active chemicals are combined with melting and dispersion agents, synergists, surfactants, and inert fillers to create Wettable Powders. Because of its dustiness, which can create major health concerns for makers and during application, strict safety measures are routinely taken. WPs also have along storage stability, are water miscible, and may be applied with ordinary spraying equipment (Brar *et al.*, 2006; Knowles, 2008).
- **WDG (Water Dispersible Granules):** It is meant to be suspended in water and solve the issues associated with WPs, as well as being dust-free and having good storage stability (Knowles, 2008; Slavica and Brankica, 2013).

Formulations in liquid form

- **Emulsion**: Emulsion formulations are designed to be blended with water and they can be either a conventional emulsion (oil in water) or an inert emulsion (water in oil). Most notably, proper emulsifier selection is required for stabilisation to avoid instability. However, losses due to evaporation and spray drift are limited in the case of water in oil emulsions due to oil in the exterior phase of the formulation (Brar *et al.*, 2006; Slvica and Brankica, 2013).
- **Suspension Concentrate (SC):** A suspension concentrate is made by dispersing finely ground solid active ingredients in a liquid phase, usually water. Because solid particles are not dissolved in liquid phase, agitation is usually required prior to application to keep particles evenly dispersed. The particle size distribution is 1-10 m, and the small particle size allows active substances to reach plant tissue more easily, improving bioefficiency. Because of the operator and environmental safety, it is a common type of formulation (Knowles, 2005; Woods, 2003).
- **Oil Dispersion (OD):** The formulations end product is made in the same way that suspension concentrate is. Instability issues could be avoided if inert ingredients were chosen carefully (Vernner and Bauer, 2007).
- **Capsule Suspension (CS):** Active chemicals are microencapsulated in a stable suspension that must be diluted with water before use. Bioagents are encapsulated in

capsules formed of gelation, starch, cellulose, and other polymers, which protect the bioagents from harsh environmental conditions. The most common method of encapsulation is the interfacial polymerization principle, which is used to produce smaller and more efficient formulations, typically fungal biopesticides (Winder *et al*, 2003).

- **Ultra Low Volume Liquids (ULV**): These are concentrates of active chemicals that are not designed to be diluted in water before use. Its light and portable, and it can be made with a suspended biocontrol agent as an active ingredient (Woods, 2003).
- **Methods of applying Biopesticides**
- Effective pest management can be done by using the right application methods and applying biopesticides at the right time and frequency. Biopesticides can be applied in a variety of ways, including:
- **Seed Treatment**: Seed treatment is the most effective method or technique for applying biopesticides. Seeds are coated with powder formulations by tumbling them with a product that is designed to adhere to the seed (Matthew *et al*., 2014; Wood, 2003).
- **Foliar application** simply refers to the spraying of biopesticides on the leaves' surface. Bean rust caused by *Uromyces phaseoli* was reduced when *B. subtillis* was applied to bean leaves.
- **Seedling Dipping**: Before transplanting, the roots of the seedlings are dipped in a biopesticide suspension for a few minutes or hours. *Trichoderma spp.*, for example, is used in this fashion.

Biopesticides mechanisms of action for pest control

The following are some of them:

1) Antibiosis
2) Competition
3) Hyperparasitism
4) Synergism

- **Antibiosis:** This is caused by an interaction with other microbes (microorganisms) that is mediated by a specific microbial metabolite, volatile chemicals, lytic enzymes or other hazardous substances (Rikita and Utpal, 2014). Antibiotics, bacteriocin, volatile compounds and metabolites are all produced by microorganisms.

- **Competition:** Biopesticides ability to compete aggressively, that is their ability to grow quickly and colonise substrate to exclude diseases is another mode of control. *T. spp*., for example, are fierce rivals of *Fusarium spp.*
- **Hyperparasitism:** is the lysis of death caused by other microbes as well as direct parasitism. *T. lignorum*, for example, has been discovered to parasitize the hyphae of *R. solani*, so soil inoculation with *Trichoderma* spores can help prevent damping off disease in citrus seedlings (Rikita and Utpal, 2014).
- **Synergism**: When a bioagent can combine the actions of hydrolytic enzymes and antibiotic secondary metabolites, it is called synergism. The effectiveness of *T. spp.* as a biocontrol agent and its fitness in the environment, for example, are due to antimicrobial compounds' synergistic effects. *Pyrones, coumarins* and other similar compounds are examples.
- **Biopesticide compatibility**
- Increased effectiveness and reduced phytotoxicity are the result of the ability to mix various pesticides without affecting their physical and chemical nature. When using a combination of biopesticides, compatibility is an important factor to consider. One of the drawbacks of biological pesticides is that they have a very limited host range and are only effective in regulated environments. The application of biopesticides alone is insufficient to reduce populations of plant-feeding insects and mites. As a result, appropriate compatible conventional pesticides can be used with biopesticides to boost their synergism. To increase toxicity, "biorational" or "low-risk" substances such as essential oil, diatomaceous earth, insect growth regulator, and related compounds can be utilized. Bt subspecies kurstaki and Bt subspecies aizawai microbial pesticide formulations were found to be efficient against a wide range of lepidopteran pests. In combination with 5% neem oil or citronella oil, Bt subspecies *kurstaki* (0.2%) is efficient against *H. armigera*. HaNPV 250 LE/ha in combination with endosulfan 0.035 percent and Fenvalerate (0.005 percent) +NPV; monocrotophos (0.035 percent) + NPV; NPV + B.t; and HNPV + NSKE (2.5 percent) were found to be effective against *H. armigera*, *S. litura*, and *L. trifolii* larvae.

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Pesticides based on *B. bassiana* and *M. anisopliae* fungus were effective on a variety of field pests when used in combination with deltamethrin or dimethoate 0.015 percent and acetamiprid 0.004 percent. Yellow fever mosquito, *Aedes aegypti*, coleopterans, and stored pests were successfully controlled with a combination of *B. bassiana* and *M. anisopliae* + pesticides. *B. bassiana* + imidacloprid and DE were effective against soil insects such as the southern mole cricket, *Scapteriscus borellii* (Kavallieratos *et al*. 2006; Sabbour *et al*. 2014), and *B. bassiana* + imidacloprid and DE were effective against soil insects such as the southern mole cricket, Scapteriscus borellii (Kavallieratos *et al*. 2006; Sabbour., 2014, Sirvi *et al*. 2013).

Factors affecting the Biocontrol Agents Success

The efficiency of biopesticides on a wide scale is challenged by a number of issues, both external and intrinsic. They are affected by external factors such as sunlight and UV radiation because they are biological agents. The photodecomposition of biopesticides is caused by ultraviolet light, which is particularly damaging. Temperature has a considerable impact and severe temperatures lead to decreased efficacy. It's challenging to keep the right temperature in the field. However, the environmental circumstances must be favourable for its survival and multiplication. The majority of fungi-based formulations are temperature and humidity sensitive, and conidia will not grow at temperatures above or below 80% relative humidity. In the case of NPV and other viruses, the sprayed solution has no effect on the pests if it adheres to the soil surface or a leaf that is not devoured by the larvae. The breakdown of certain pesticide active components frequently involves a combination of hydrolysis and photodecomposition. The faster the pesticide is hydrolyzed, the less time it is available in the environment. Biopesticides are also affected by leaching. If an acidic pesticide is sprayed to an alkaline surface or vice versa, the pesticide may quickly degrade. As a result, the soil pH and biota play a role in the effectiveness of biopesticides. Rain during biopesticide application washes the pesticide off the plant, reducing its effectiveness. Because some biopesticides are incompatible with chemical pesticides, their effectiveness is reduced. When releasing biocontrol agents, the compatibility of biopesticides with predators and parasitoids must also be considered. Phytochemicals antagonistic effects on biopesticides must also be recognized.

Biopesticides provide a number of advantages

The benefits or advantages linked with biopesticides have piqued people's curiosity. They are as follows:

1) Biopesticides are typically less harmful and generate less damage in the environment.
2) As opposed to chemicals that have a broad spectrum of activity, they are designed to target only one specific pest or in some cases, a few target pests.
3) Generating biopesticides is much less expensive than developing synthetic chemical pesticides.
4) Their control is preventative rather than curative, and their effects on flowers are minimal.

Biopesticides have Drawbacks

1) The target pest/pathogen has a high degree of specificity, which may necessitate a precise identification.
2) Biopesticides are typically unsuitable if a pest epidemic occurs quickly and poses a hazard to crops due to their slow speed of action.
3) Biopesticides are not suitable for use as a stand-alone therapy; instead, they must be used in conjunction with another approach to achieve high efficacy.
4) Living organisms evolve and become more resistant to biological, chemical, physical, and other forms of control as time goes on.

Conclusion

Consumer and government concerns about the difficulties linked with synthetic pesticides for pest management and food safety have prompted growers to seek for innovative environmentally acceptable alternatives to the present chemical-based procedures. Biopesticides have emerged as a viable alternative to chemical pesticides, and their demand is gradually increasing throughout the world. As a result, this paper has offered some information regarding the potentials of "biopesticides for pest control," which, if completely realized, may be a very successful alternative strategy for pest control as well as an important component of integrated pest management.

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