Role of biopesticides to manage insect pests in sustainable agriculture: A review

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Abstract

In present scenario the rapid increase in population and demand of food materials has initiated the large use of pesticides. An ecofriendly alternative to chemical pesticides is biopesticides, which encompasses a broad array of microbial agents, biochemicals derived from micro-organisms and other natural sources, and processes involving the genetic incorporation of DNA into agricultural commodities that confer protection against pest damage. Biopesticides fall into three major classes namely, biochemical, plant-incorporated protectants, and microbial pesticides. Bio-pesticides are ecofriendly pesticides which are obtained from naturally occurring substances, microbes and plants. Biopesticides being target pest specific are presumed to be relatively safe to non-target organism including humans. However, in India, some of the biopesticides like Bacillus thuringiensis (Bt), Nuclear Polyhedrosis Virus (NPV), Beauvaria bassiana, Metarhizium sp. and Verticillium sp. and neem-based pesticides etc. have already been registered and are being practiced. Also in India, there are many locally available plants like Ipomoea, Neem, Garlic, Pinus, Cassia, Eucalyptus etc. which can be easily processed and increase the biopesticide uses in India. Through this review, I attempt to highlight the role of biopesticides in agriculture and potential biopesticide available in India and how we can maximize the use of biopesticide for sustainable agriculture.

Keywords: chemical pesticides, biopesticides, ecofriendly

Introduction

Biopesticide is a formulation made from naturally occurring substances that controls pests by non toxic mechanisms and in ecofriendly manner; hence gaining importance all over the world. In very general terms, according to the US Environmental Protection Agency (USEPA), biopesticides are pesticides derived from natural materials, such as, animals, plants, bacteria, and minerals. Biopesticides also include living organisms that destroy agricultural pests. Biopesticides may be derived from animals (e.g. nematodes), plants (e.g. Chrysanthemum, Azadirachta) and micro-organisms (e.g. Bacillus thuringiensis, Trichoderma, nucleopolyhedrosis virus), and include living organisms (natural enemies), their products (phytochemicals, microbial products) or byproducts (semiochemicals) which can be used for the management of pests injurious (Hajeck, et al., 1994) [13].

The time-tested indigenous technical knowledge (ITK) of using natural materials for the control of pests has been very effective but due to the introduction and uses of chemical pesticides many ITKs have been forgotten. Biopesticides pose less threat to the environment and human health. They are generally less toxic than chemical pesticides, often target specific, have little or no residual effects and have acceptability for use in organic farming.

Types of Biopesticides

The USEPA separates biopesticides into three major classes based on the type of active ingredient used, namely, biochemical, plant-incorporated protectants, and microbial pesticides (USEPA 2008) [35].

I. Microbial pesticides

Microbial pesticides are also known as biocontrol agents (BCAs). They offer the advantages of higher selectivity and lower or no toxicity in comparison to conventional chemical pesticides (MacGregor, 2006) [21]. Microbial pesticides consist of microorganisms (bacteria, fungi, viruses, or protozoans) as the active-ingredient, and they have been successfully used in
controlling insect pests. Though each microbial active ingredient is relatively specific for its target pest, microbial pesticides can control many different kinds of pests. For example, there are fungi that control certain weeds, and other fungi that kill specific insects. The most widely known microbial pesticides are varieties of the bacterium *Bacillus thuringiensis* (Bt), which can control certain insects in cabbage, potato, and other crops. Bt produces a protein that is harmful to specific insect pest. Certain other microbial pesticides act by out-competing pest organisms. Microbial pesticides need to be continuously monitored to ensure that they do not become capable of harming non-target organisms, including humans.

II. Plant- Incorporated-Protectants (PIPs)

PIPs are pesticidal substances that plants produce from genetic material that has been added to the plant. For example, scientists can take the gene for the Bt pesticidal protein, and introduce the gene into the plants own genetic material. Then the plant, instead of the Bt bacterium manufactures the substance that destroys the pest. Both the protein and its genetic material are regulated by EPA; the plant itself is not regulated.

III. Biochemical pesticides

These are naturally occurring substances, such as, plant extracts, fatty acids or pheromones that control pests by non-toxic mechanisms. Conventional pesticides, by contrast, are synthetic materials that usually kill or inactivate the pest. Biochemical pesticides include substances that interfere with growth or mating, such as plant growth regulators, or substances that repel or attract pests, such as pheromones. Because it is sometimes difficult to determine whether a natural pesticide controls the pest by a non-toxic mode of action, EPA has established a committee to determine whether a pesticide meets the criteria for a biochemical pesticide.

Use of Bio-Pesticides to Manage Insect Pests

Bio-pesticides have been used solely or in combination against important crop pests in diverse agro-ecosystems. This review illustrates some selected examples of case studies on the effective utilization of bio-pesticides in pest management programme.

I. Microbial Pesticides

A) Use of entomopathogenic fungi

Entomopathogenic fungi are important natural regulators of insect populations and have potential as mycoinsecticide agents against diverse insect pests in agriculture. These fungi infect their hosts by penetrating through the cuticle, gaining access to the hemolymph, producing toxins, and grow by utilizing nutrients present in the haemocoel to avoid insect immune responses (Hajeck, 1994) [13]. Entomopathogenic fungi may be applied in the form of conidia or mycelium which sporulates after application. The use of fungal entomopathogens as alternative to insecticide or combined application of insecticide with fungal entomopathogens could be very useful for insecticide resistant management (Hoy, 1999) [14].

The commercial mycoinsecticide ‘Boverin’ (Cherkasybiozakazhst) based on *B. bassiana* with reduced doses of trichlorophen have been used to suppress the second-generation outbreaks of *Cydia pomonella* L. (Ferron, 1971) [11]. (Anderson, et al., 1989) detected higher insect mortality when *B. bassiana* and sublethal concentrations of insecticides were applied to control Colorado potato beetle (*Leptinotarsa decemlineata*), attributing higher rates of synergism between two agents. A long term example of a classical biological control project using fungi is the program targeting the cassava green mite (CGM), *Mononychellus tanajoa* (Bondar) in Africa. In 1988, the exploration for potential natural enemies in Brazil revealed that the entomophthoralean *N. tanajoae* was one of the most important natural enemies of CGM in northeastern Brazil (Delalibera, et al, 1992) [19]. During the last 20 years, a series of studies was undertaken to make the release of this pathogen in Africa possible. The impact of the fungus *Neozygites floridana* on the tomato red spider mite, *Tetranychus evansi* Baker & Pritchard was demonstrated in the field and under greenhouses during four crop cycles of tomato and nightshade (Duarte, et al, 2009) [10] in Piracicaba, SP, Brazil. The effectiveness of seven strains of entomopathogenic fungi against *Ceratitis capitata* adults was evaluated in the laboratory (Castillo, et al, 2000) [8]. Adults were susceptible to five of seven aqueous suspensions of conidia. The extract from *M. anisopliae* was the most toxic, resulting in about 90% mortality. The compatibility of the entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin with neem was conducted against sweet potato whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), on egg plant (Islam, et al, 2009) [20]. The combination of *B. bassiana* and neem yielded the highest *B. tabaci* egg and nymph mortalities and the lowest LT50 value. Therefore, neem was used along with *B. bassiana* suspension as an integrated pest management program against *B. tabaci*. The use of the insect-pathogenic fungus *Metarhizium anisopliae* against adult *Aedes aegypti* and *Aedes albopictus* mosquitoes has also been reported (Scholte, et al, 2007) [28].

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Two isolates of entomopathogenic fungi, *Beauveria bassiana* SGI8702 and *Paecilomyces fumosoroseus* Prf153 were also bioassayed against *T. cinnabarinus* eggs (Weibin, et al, 2004) [56]. Entomopathogenic fungi could provide a viable component for an integrated pest management strategy for control of *B. cockerelli* and other potato pest insects. Commercial formulations of *Metarhizium anisopliae* and *Isaria fumosorosea* and abamectin were conducted. It was observed that all fungal treatments significantly reduced plant damage and zebra chip symptoms.
B) Use of Virus biopesticides
First well-documented introduction of baculovirus into the environment which resulted in effective suppression of a pest occurred accidentally before the World War II. Along with a parasitoid imported to Canada to suppress spruce sawfly Diprion hceryniae, an NPV specific for spruce sawfly was introduced and since then no control measures have been required against this hymenopteran species. In the past, the application of baculoviruses for the protection of agricultural annual crops, fruit orchards and forests has not matched their potential. The number of registered pesticides based on baculovirus, though slowly, increases steadily. At present, it exceeds fifty formulations, some of them being the same baculovirus preparations distributed under different trade names in different countries. NPVs and GVs are used as pesticides but the group based on nucleopolyhedrosis viruses is much larger. The first viral insecticide ElearTM was introduced by Sandoz Inc. in 1975 (Ignoffo, et al, 1981). The well-known success of employing baculovirus as a biopesticide is the case of Anticarsia gemmatalis nucleopolyhedrovirus (AgMNPV) used to control the velvet been caterpillar in soybean. In the early eighties this program was performed in Brazil. Since then, over 2,000,000 ha of soybean have been treated with the virus annually. Recently, after many new emerging pests in the soybean, this number dropped down. Although the use of this virus in Brazil is the most impressive example of viral bioregulation worldwide, the virus is still obtained by in vivo production mainly by infection of larvae in soybean farms. Many other species belonging to the Noctuidae family are economically important pests of sugarcane, legume, rice and others. Autographa californica and Anagaphra falcifera NPVs were registered in the USA and were field-tested at a limited scale. These two NPVs have relatively broad host spectrum and potentially can be used on a variety of crops infested with pests belonging to a number of genera, including Spodoptera and Helicoverpa. The well-known success of employing baculovirus as a biopesticide is the case of Anticarsia gemmatalis nucleopolyhedrovirus (AgMNPV) used to control the velvetbeen caterpillar in soybean (Moscardi, 1999). On the basis of this spectacular success of a baculovirus pesticide, it is needless to say that the advantages of biopesticides over chemical pesticides are numerous (Mettenmeyer, et al., 2002) [23].

C) Use of Protozoa biopesticides
Protozoan pathogens naturally infect a wide range of insect hosts. Although these pathogens can kill their insect hosts, many are more important for their chronic, debilitating effects. One important and common consequence of protozoan infection is a reduction in the number of Offsprings produced by infected insects. Although protozoan pathogens play a significant role in the natural limitation of insect populations, few appear to be suited for development as insecticides. As another example, the Microsporidia include species promising for biological control. Microsporidian infections in insects are thought to be common and responsible for naturally occurring low to moderate insect mortality. But these are indeed slow acting organisms, taking days or weeks to make harm their host. Frequently they reduce host reproduction or feeding rather than killing the pest outright. Microsporidia often infect a wide range of insects. Some microsporidia are being investigated as microbial insecticides, and at least one is available 294 Current Progress in Biological Research commercially, but the technology is new and work is needed to perfect the use of these organisms (Hoffmann, et al., 1993) [14].

D) Use of bacterial bio-pesticides
Bacterial bio-pesticides are probably the most widely used and cheaper than the other methods of pest bioregulation (Singh et al, 2011; Singh et. al. 2012) [12, 13]. Insects can be infected with many species of bacteria but those belonging to the genus Bacillus are most widely used as pesticides. One of the Bacillus species, Bacillus thuringiensis, has developed many molecular mechanisms to produce pesticidal toxins; most of toxins are coded for by several cry genes (Schneff, et al., 1998) [3]. Since its discovery in 1901 as a microbial insecticide, Bacillus thuringiensis has been widely used to control insect pests important in agriculture, forestry and medicine. Its principal characteristic is the synthesis, during sporulation, of a crystalline inclusion containing proteins known as endotoxins or Cry proteins, which have insecticidal properties. To date, over one hundred B. thuringiensis-based bioinsecticides have been developed, which are mostly used against lepidopteran, dipteran and coleopteran larvae. In addition, the genes that code for the insecticidal crystal proteins have been successfully transferred into different crops plants, which have led to significant economic benefits. Because of their high specificity and their safety in the environment, B. thuringiensis and Cry proteins are efficient, safe and sustainable alternatives to chemical pesticides for the control of insect pests (Roh, et al., 2007; Kumar, et al., 2008) [26, 17]. The toxicity of the Cry proteins has traditionally been explained by the formation of transmembrane pores or ion channels that lead to osmotic cell lysis (Roh, et al., 2007) [26]. In addition to this, Cry toxin monomers also seem to promote cell death in insect cells through a mechanism involving an adenyl cyclase/PKA signaling pathway (Zhang, et al., 2006) [37]. However, despite this entomopathogenic potential, controversy has arisen regarding the pathogenic lifestyle of B. thuringiensis. Recent reports claim that B. thuringiensis requires the co-operation of commensal bacteria within the insect gut to be fully pathogenic (Broderick, et al., 2006) (Broderick, et al., 2009) [4, 5]. In clear opposition, genomic and proteomic studies have been argued as the most solid data to convincingly demonstrate that B. thuringiensis is a primary pathogen rather than a soil-dwelling saprophyte. In any case, what is certainly not doubtful is that B. thuringiensis is one of the most successful examples of the use of microorganisms in agricultural biotechnology and will continue to be one of the most important microbial weapons to defend our crops from insect pests (Awasthi, 2019) [1]. At the end of the twentieth century worldwide sales of bacterial pesticides amounted to about 2% of the total global insecticide market but their share in pesticide market steadily increases.

II. Plant-Incorporated-Protectants (PIPs)
One approach, to reduce destruction of crops by phytophagous arthropod pests, is to genetically modify plants to express genes encoding insecticidal toxins. The adoption of genetically modified (GM) crops has increased dramatically in the last 11 years. Genetically modified (GM) plants possess a gene or genes that have been transferred from a different species. The production of transgenic plants that express insecticidal δ-endotoxins derived from the soil bacterium Bacillus...
Neem
Neem tops the list of 2,400 plant species that are reported to have pesticidal properties and is regarded as the most reliable source of eco-friendly biopesticidal property. Neem products are effective against more than 350 species of arthropods, 12 species of nematodes, 15 species of fungi, three viruses, two species of snails and one crustacean species (Nigam, et. al., 1994) [23]. Azadirachtin, a tetranortriterpenoid, is a major active ingredient isolated from neem, which is known to disrupt the metamorphosis of insects (Tomlin, et al., 2007) [34]. Two tetracyclic triterpenoids - melianetetraolone and odoratone isolated from neem exhibited insecticidal activity against Anopheles stephensi (Siddiqui, et al., 2003) [30]. Neem seed kernel extract (NSKE) was found most effective in reducing the larval population of Helicoverpa armigera in chickpea and pod damage (Bhushan, et al., 2011) [9]. Neem formulations also have a significant effect against eggs of peach fruit fly Bactrocera zonata (Saunders). Over 195 species of insects are affected by neem extracts and insects that have become resistant to synthetic pesticides are also controlled with these extracts. The apprehension that largescale use of neem based insecticides may lead to resistance among pests, as being observed with synthetic pesticides, has not been proved correct. Neem bio-pesticides are systemic in nature and provide long term protection to plants against pests. Pollinator insects, bees and other useful organisms are not affected by neem based pesticides. Neem seed water extract is found to be very potent in combating various pests of storage and field crops in Sudan, and recommended for use in small holding farms (Abdalla, et al., 2010).

Neem-cow urine extract composition of 5 kg of neem leaves, 5 lit of cow urine, 2 kg of cow dung, 100 lit of water. Crush all ingredients and ferment for 24 hours with intermittent stirring, filter and squeeze the extract and dilute to 100 lit of water. Use this extract to fill in the spray machine and spray it over one acre of the crop. Neem acts in various ways like as antifeedant, repellent, growth inhibitor, and as oviposition deterrent. Cow urine has high content of urea in it which is toxic to most of organisms, the pests and insects etc. (Kumawat, et al., 2014) [19].

Garlic
Extracts of garlic have proved effective against Alternaria spp., powdery mildew, black spot, Phytophthora, Fusarium spp. and bacterial pathogens like Pseudomonas. The National Research Center for Onion and Garlic, Pune, Maharashtra is conducting research on this pesticide. Mode of action as well as the fungicidal and insecticidal properties of garlic might be partly due to enzyme inhibition. Bio-efficacy tests were conducted against major pests of vegetables like gherkins and potatoes and plantation crops like cashew (Anacardium occidentale) and coconut (Cocos nucifera L.). Garlic biopesticides have the unique property of repelling and preventing the insects from feeding especially the sucking pests. The biopesticide is compatible with chemical insecticides and fertilizers. The garlic biopesticide not harmful to natural enemies, pollinators and other beneficials, are cheaper and compatible with other organics and chemicals. In South Karnataka (2005-2009) possibilities of using garlic based biopesticide as an IPM tool explored. They can form an important IPM tool in sustainable and organic cultivated farming system (Chakravarthy, 2005-2009) [7].

Chili–garlic extract
Ipomoea nil (Morning glory) leaves 1 kg, 500 gm hot chili, 500 gm garlic, 5 kg neem leaves, 10 lit cow urine. Crush all ingredients and boil the suspension till it becomes half of the initial. Filter and squeeze the above extract and store it in glass or plastic bottles. Take 2-3 lit of the extract and dilute it with 50 lit of water. Now mix it thoroughly and use it as a foliar spray for one acre of crop. Garlic contains sulphur which is an antibacterial. Chili has the property to avoid fungal and bacterial infection due to its preservative property (Kumawat, et al., 2014) [19].

Pheromones as insect pest control
Pheromones are chemicals emitted by living organisms used to send messages to individuals - usually of the opposite sex - of the same species. Pheromones of hundreds of insect species have been chemically elucidated, including the sex pheromone of the codling moth. When used in combination with traps, sex pheromones can be used to determine what insect pests are present in a crop and what plant protection measures or further actions might be necessary to assure minimal crop damage. If the synthetic attractant is exceptionally effective and the population level is very low, some control can be achieved with pheromone traps or with the “attract and kill” technique. Generally, however, mating disruption is more effective. Synthetic pheromone that is identical to the natural version is released from numerous sources placed throughout the crop to be protected. Mating disruption has been successful in controlling a number of insect pests. More than 20 percent of the grape growers in Germany and Switzerland use this technique and produce wine without using insecticides. In the United States, mating disruption has proven effective in codling moth, navel orangeworm, pink bollworm, Oriental fruit moth, European grape moth, and grapevine moth, to name a few. More than 40 percent of the fruit tree acres in the western U.S. are treated with mating disruption for caterpillar control. Efforts to control the pink bollworm, Pectinophora gossypiella (Saunders), by mating disruption began with the sex attractant "hexulure" in the early 1970's. The discovery of the pink bollworm sex pheromone in 1973 led to the first successful commercial formulation in 1978 (Baker, et al., 1991) [21]. An inhibitor-based tactic was demonstrated to suppress infestations of the southern pine beetle, Dendroctonus frontalis Zimmermann (Salom, et al., 1995).
Biopesticides Use in India
Biopesticides represent only 2.89% (as on 2005) of the overall pesticide market in India and is expected to exhibit an annual growth rate of about 2.3% in the coming years (Thakore, 2006). In India, so far only 12 types of biopesticides have been registered under the Insecticide Act, 1968. Neem based pesticides, Bacillus thuringiensis, NPV and Trichoderma are the major biopesticides produced and used in India. Whereas more than 190 synthetics are registered for use as chemical pesticides. Most of the biopesticides find use in public health, except a few that are used in agriculture. Besides, i) transgenic plants and ii) beneficial organisms called bio-agents: are used for pest management in India (Mazid, et al., 2011) [2]. The potential benefits of using biopesticides in agriculture and public health programmes are considerable. Biopesticides do not have residue problem which is a matter of significant concern for consumers, particularly for fruits and vegetables. When used as a component of IPM, efficacy of biopesticides can be equal to the conventional pesticides, especially for crops like fruits, vegetables, nuts and flowers. By combining performance and environmental safety, biopesticides perform efficaciously with the flexibility of minimum application restrictions, and superior resistance management potential (Kumar, 2012) [18]. The interest in biopesticides is based on the advantages associated with the products which are as follows:
1. Host specificity.
2. Often effective in very small quantity.
3. Naturally and quickly decomposable.
4. No problem of toxic residue.
5. No problem of cross resistance.
6. Conventional technique or methods for applications.
7. Permanent control of pest or long persisting effect.
8. Ideally suited for integration with most other plant protection measures used in IPM programme.
9. No fear of environment pollution and hence ecofriendly.

From above study we can understand very well that the use of biopesticides to control insect pests may play a vital role in maintaining quality of food for health of human beings and their livestock, environmental protection for sustainable development.

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