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Role of bio-pesticides in recent trends of insect pest management: A review

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Abstract
Agricultural crops has had to face the destructive activities of numerous pests like fungi, weeds and insects from time immemorial, leading to radical decrease in yields. For the control of these pests chemicals are highly effective because only they act on a broad host range but their is also a negative impact on the environment and the overall sustainability of the farming systems. Use of synthetic pesticides has severely affected both the abiotic and biotic components of the environment. Managing agricultural production systems on a sustainable basis is one of the most critical challenges for the future of humanity as the world population is increasing exceptionally. Biopesticides is a potential tool considered to be the best alternative to synthetic pesticides that are highly effective, target specific and reduce environmental risks. Biopesticides are derived from animals, plants and other natural materials such as fungi, bacteria, algae, viruses, nematodes and protozoa. The advance research and development in the field of biopesticides applications greatly mitigate environmental pollution. The development of biopesticides stimulates modernization of agriculture and will, without doubt, gradually replace chemical pesticides. The current status and advancement of biopesticides focusing mainly on improving action spectra, replacing of chemical pesticides, its role in integrated pest management, use of botanical and semiochemical in pest management have been discussed in this review.

Keywords: Biopesticides, synthetic pesticides, sustainability, environmental pollution

Introduction
Agriculture is our groundwork of Indian economy and contributes 15% GDP. It majorly fulfill the food demand of increasing population with diminishing cultivable land resource. The global population is projected to reach 8.5 billion by 2030, 9.7 billion by 2050 and exceed 11 billion in 2100 [1]. In order to accomplish the food demand of growing population there is need to develop an advanced agriculture production system with sustainable approach. The Appropriate pest management is very important factor for healthy development of crop. Pesticides have been the most effective weapons and play vital role in crop protection against agricultural insect-pests. Excessive and continuous use of chemicals during green revolution technology has been proved impressive but indiscriminate use of chemical fertilizers and pesticides has resulted in several undesirable effects on the human health, environment, phytotoxicity, resistance, residue problems, resurgence and the overall sustainability of the farming systems. Currently the concept of the ideal pesticide has significantly changed to include (i) a high selectivity to target species but a minimal toxicity to non-target organisms, (ii) a high effectiveness at low application rates, (iii) a low environmental persistence or biodegradable to avoid bioconcentration and biomagnification within food chain. The focus on insecticide research shifted to search for and development of new green chemistries (biopesticides). Biopesticides are effective, eco friendly, biodegradable and reduced frequently application of synthetic insecticides for pest management [19]. Since the advent of biopesticides, a large number of products have been registered and released, some of which have played a leading role in the agro-market. Nowadays, a lot of biopesticides have been developed from microorganisms (bacteria, fungi, viruses, etc.), plant, animal derived products (pheromones, hormones, insectspecific toxins, etc.) and genetically modified organisms are used worldwide for insect pest management. The aim of this review is to critically highlight the potentials of biopesticides for pest control.

Biopesticides
Biopesticides are derived from fungi, bacteria, algae, viruses, nematodes and protozoa or naturally occurring substances from living organisms (natural enemies) or their products (microbials, phytochemicals) or their by-products (semiochemicals) that can control pest by nontoxic mechanisms [19].

Up to now, there are more than 3000 kinds of microbes that cause diseases in insects. Organization for Economic Co-operation and Development, viewed biopesticides as manufactured mass produced agents derived from natural source living micro-organisms and sold for use to control pests. According to [20], biopesticides encpmpass a abroad array of microbial pesticides, biochemicals obtained from micro-organisms and natural sources. However, a lot of research should be conducted to find remaining undiscovered or unidentified microorganisms that are useful in insect pest management [18]. Over 100 bacteria have been identified as insect pathogens, among which *Bacillus thuringiensis* Berliner (Bt) has got the maximum importance as microbial control agent [28]. So far, more than 1000 insect species viruses have been isolated such as nuclear polyhedrosis virus (NPV) infested 525 insects worldwide. Over 800 species of entomopathogenic fungi and 1000 species of protozoa pathogenic have been described and identified. The two major groups of entomopathogenic nematodes are *Steinernema* (55 species) and *Heterorhabditis* (12 species) [5].

Categories of Biopesticides

Biopesticides fall into four major categories:

1. Microbial pesticides
2. Botanical pesticides
3. Plant-Incorporated Protectants (PIPs)
4. Semiochemicals

Microbial pesticides: These consist of microorganisms such as bacterium, virus, fungus, protozoan as active ingredients which are used for the biological control of plant pathogens, pestiferous insects and weed. The most widely used microorganism in the development of biopesticide is the insect pathogenic bacterium *Bacillus thuringiensis* (Bt). This bacterium serves as an insecticide for most Lepidoptera, coleopteran and diptera [22]. *B. thuringiensis* produces protein crystals or toxin during spore formation of the bacterium that is capable of lysis of gut cells when consumed by a specific or susceptible insect [23]. Baculoviruses are double-stranded DNA viruses present in arthropods, mainly insects. Baculoviruses are highly pathogenic against numerous serious insect pests. In Lepidoptera, i.e., the primary group where baculoviruses have been isolated, they only cause mortality in the larval Stage [9]. Two groups of baculoviruses exist: the nucleopolyhedroviruses (NPVs) and granuloviruses (GVs) [4]. Several entomopathogenic fungi and their derivatives are also used as microbial pesticides [21]. *Metarhizium anisopliae* are hyphomycete entomopathogenic fungi most widely used for insect pest control and are ubiquitous worldwide [8]. This species comprises a huge number of different strains and isolates of various geographical origins and from different types of hosts [12].

Table 1: List of important microbial biopesticides [31]

Target insects	Common name and references
Entomopathogenic viruses	
Helicoverpa zea: corn earworm, tomato fruitworm, tobacco budworm, *Helioth virescens*	Corn earworm NPV (HezeSNPV)
Helicoverpa armigera, cotton bollworm, pod borer	Cotton bollworm NPV (HearNPV)
Plutella xylostella	Diamond back moth GV
*Anticarsia gemmatal*is	Velvetbean caterpillar, NPV (AngeMNPV)
Noctuidae	Alfalfa looper NPV (AucaMNPV)
Buzura suppressaria	Tea moth (BuzuNPV)
Entomopathogenic bacteria	
Lepidoptera	*Bacillus thuringiensis* subspecies kurstakia
Lepidoptera	*B. thuringiensis* sub-species aizawaia
Coleoptera: Scarabaeidae	*B. thuringiensis* sub-species japonensis
Coleoptera: Scarabaeidae, *Popillia japonica*	*Paenibacillus popilliae*
Entomopathogenic fungi	
Hemiptera	*Aschersonia aleyrodis*
Coleoptera (Scarabaeidae)	*Beauveria brongniartii*
Hemiptera, Thysanoptera	*Conidiobolus thromboides* Acari
Hemiptera	*Lecanicillium longisporum*
Lepidoptera	*Nomuraea rileyi*
Coleoptera, Diptera, Hemiptera, Isoptera	*Metarhizium anisopliae sensu* lato

Botanical Pesticides: They are also known as herbal pesticides [24] are naturally occurring substances used for controlling pests through a non-toxic mechanism and because it is difficult sometimes to assessed whether a natural pesticide can control the pest by a non-toxic mode of action, Environmental Protection Agency [10] has established a committee to determine whether a pesticide meets the specified criteria for a biochemical pesticides [19]. Plants that produced secondary metabolites are also considered as biopesticides [27]. Over 6000 plant species have been identified that possessing insecticidal properties. In insect pest management, a number of plant products derived from neem, custard apple, tobacco, pyrethrum, etc. have been used as safer insecticides [5]. Botanical pesticides have environmentally friendly characteristics such as volatile nature, low environmental risk compared to current synthetic pesticides. Due to minimal residual activity; predation, parasitism, and the number of pollination insects would affect smaller and compatible with IPM programs [6].

Table 2: Some plant products used as biopesticides [19]

Plant product used as biopesticides	Target pests
Limonene and Linalool	Fleas, aphids and mites, also kill fire ants, several types of flies, paper wasps and house crickets
Neem	A variety of sucking and chewing insect
Pyrethrum /Pyrethrins	Ants, aphids, roaches, fleas, flies, and ticks
Rotenone	Leaf-feeding insects, such as aphids, certain beetles (asparagus beetle, bean leaf beetle, Colorado potato beetle, cucumber beetle, flea beetle, strawberry leaf beetle, and others) and caterpillars, as well as fleas and lice on animals
Ryania	Caterpillars (European corn borer, corn earworm, and others) and thrips
Sabadilla	Squash bugs, harlequin bugs, thrips, caterpillars, leaf hoppers, and stink bugs

Plant-Incorporated-Protectants (PIP): PIPs, also known as Genetically Modified Crops, are biopesticidal substances produced by plants from genetic material that have been added or incorporated into their genetic makeup. A typical example of this is the use of Bt protein to develop PIP in a process called genetic engineering. The Bt toxin is host specific and is capable of causing death within a short time, usually 48 hours [26]. Safe to beneficial organisms, human, environment and it does not harm vertebrates [25].

Semiochemicals: A semiochemical by definition is a chemical signal produced by one organism, usually insects which caused a behavioural change in an individual of the same or different species. For crop protection, the most widely used semiochemicals are the insect pheromones which serve as a signal to communicate with others in their species for a number of reasons and synthesized for pest control by mating disruption, Lure-and-Kill systems and mass trapping [18]. Insects produce chemicals called pheromones to stimulate a certain behavioral reaction from other individuals. These pheromones have numerous effects and are named according to their evoked response, for example, sex pheromones, aggregation pheromones, alarm pheromones, etc. A few pheromones function as sex attractants, permitting individuals to detect and locate mates, whereas others induce trail following, oviposition, and aggregation in other congeners. Pheromones have become essential tools for monitoring and controlling agricultural pest populations, and as such, a huge collection of over 1,600 pheromones and sex attractants has been reported [16]. Nowadays, pheromones and other semiochemicals are applied to monitor and control pests in millions of hectares. There are several advantages of utilizing pheromones for monitoring pests, including lower costs, specificity, ease of use, and high sensitivity [14, 15, 17]. Insect pest monitoring by using pheromone lures can profit management conclusions such as insecticide application timing [11, 13]. Pheromones produced by insects are highly species specific. Virgin female insects are developing sex pheromones when expecting for a mate and males along the concentration slope for the female producer. Aggregation pheromones are released by insects such as wood-invading beetles to show to others the presence of a good food source [29].

Role of biopesticides in IPM

Crop protection has relied basically on synthetic chemical pesticides in past, but their availability is now declining as a result of new laws and legislations and the evolution in the process of insect resistance. Therefore, it is necessary to replace the pest management strategy. Biopesticide is the best alternative to synthetic chemical pesticides based on living micro-organisms or natural products. Biopesticides include a broad array of microbial pesticides, biochemicals derived from microorganisms and other natural sources, and processes involving the genetic modification of plants to express genes encoding insecticidal toxins [19]. Biopesticides have demonstrated the potential of pest management and used worldwide. In the European Union, there are new opportunities for development of biological pesticides in combination with integrated pest management, ecological science and post genomic technologies [23]. In this regard, the use of biopesticides and bio-agents has assumed significance as an important component of IPM due to their economic viability and eco-friendly nature instead of chemical synthetic pesticides [2]. Biopesticide application as a component of IPM programs can play important role in overcoming disadvantage of chemical insecticides that have some important characteristics such as biodegradable and self- perpetuating, less harmful on beneficial pests, mostly host specific and less shelf life [7]. Baculovirus biopesticides are an alternative to chemical pesticides in integrated pest management; however, they have a wide range of difficulties for commercial uses such as slow killing, short life time, high production costs and current laws and regulations of biological control agents [3]. To overcome many problems of wild-type baculoviruses, many strategies have been developed to improve their killing action by recombinant DNA technology, including the insertion of genes encoding insect hormones or enzymes, or insect-specific toxins [4].

Future prospects: The biopesticide market will continue to grow in future due to increased pest resistance problem and high demand of safe and quality food products. However, there are many challenges that will need to be overcome. Biopesticides clearly draw attention as safer alternative to manage pest and diseases while posing less risk to human being and the environment. In the US, biopesticides are monitored by Environmental Protection Agency which supports their registration, sale and distribution under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as well as ensures a “reasonable certainty of no harm” under the Federal Food, Drug, and Cosmetic Act (FFDCA) to provide pesticide residue-free food and feed [30]. Most of the times, it is the farmers who are affected by the problems of pesticide resistance and withdrawal of plant protection products, and yet they are ‘policy taker’ rather than ‘policy makers’. Hence, a public-private sector approach to the development, manufacturing and sale of environment friendly alternatives to chemical pesticides for developing countries like India is the need of the day.

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