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Role of Microbial and Biopesticides in Plant Protection

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Abstract: Extensive and inappropriate pesticide use has caused pest resistance to major groups of pesticides, resurgence of secondary pests, high pesticide residue in the produce and decimation of natural enemies. Their excessive use has caused adverse effects on human beings and environment. An ecofriendly alternative to chemical pesticides is biopesticides. Biopesticides are natural, biologically occurring compounds that are used to control various agricultural pests infesting plants in forests, gardens, farmlands, etc. There are different types of biopesticides that have been developed from various sources. Botanical pesticides are assumed to be effective against various crop pests, and they are easily biodegradable and available in high quantities and at a reasonable cost. Plants and microbes are the important components of ecosystem, and their interactions help in regulating the biogeochemical cycle in the environment. Plant-associated microorganisms include bacteria, fungi, and viruses use host plants for their growth, colonization, and proliferation; however, they offer a variety of benefits to the hosts. These microbes are not harmful to the plants; however, they secrete some beneficial substances which may help in plant growth promotion, resistance to pathogenic microbes, removal of harmful contaminants, and production of secondary metabolites.
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Introduction

According to the Food and Agriculture Organization (FAO), the estimate of the world population for 2001 was 6.134×10^9 inhabitants (http://apps.fao.org) and the projection towards 2025 is nearly 8.5×10^9 inhabitants. Such an increase, which will occur mainly in developing countries, will inevitably require an additional agricultural production of 2.4×10^9 t/year. However, this additional production should not be based on an increase in the arable surface taken from temperate or rain forest, but on the improvement of crop productivity. This can be achieved in part by suitable control of losses due to biotic agents (pests, diseases, weeds), which on average are estimated to be 38–42% of the potential production (Andrew et al., 2000). Currently, the control of plant pests, diseases and weeds is achieved mainly by spraying crops with a vast amount of synthetic chemical pesticides (Zafar et al., 2020; Cook et al., 2000; Qasim et al., 2022). Concerns over the impacts of some of the chemical based pesticide products on both human health and the environment in the world. It contributes to a plethora of issues such as farmers' health risks (Damalas and Eleftherohorinos, 2011) and food safety issues (Travisi and Nijkamp, 2008). Extensive use of chemical pesticides may lead to reduced biodiversity (van der Sluijs et al., 2015), destruction and loss of pest natural enemies, pollinators, and other non-target organisms (Mancini et al., 2019) and emergence of pest resistance (Onstad, 2014). Concurrent with the removal of some of the more toxic compounds has been the development of alternative crop protection approaches such as integrated crop or pest management (ICM or IPM) which makes use of biological crop protection agents (BCA) (Zafar et al., 2020; Cherry and Gwynn 2007). Microbial pesticides account for many of these newer crop protection agents and include products based on fungi, bacteria, viruses, and protozoa with activity against insect pests, diseases, and occasionally weeds. Products based on Bacillus thuringiensis (Bt) are the longest established and most dominant microbial pesticides available. Bt-based products are available worldwide, registered using the chemical plant protection pathway. One factor influencing the use and performance of microbial control agents (bacteria, viruses, fungi, nematodes or protozoa) is the susceptibility to ultra-violet (UV) radiation. In the past, several authors have argued that the main advantages of microbial pesticides compared to chemical products are (a) the absence of harmful residues, (b) the environmental friendly nature, and (c) the low production cost (Ren et al., 2019; Bonaterra et al., 2011). Based on a report by Business Communications Company (BCC), Inc., research on the global biopesticide and synthetic pesticide market showed that it was worth USD 61.2 billion in 2017 and is expected to rise to approximately USD 79.3 billion by 2022. Therefore, an eco-friendly alternative is the need of the hour. Improvement in pest control strategies includes higher quality and greater quantity of agricultural products. Therefore, there is a great need to develop effective, biodegradable and environment-friendly biopesticides. Priority should be given to biopesticide use against pests to avoid adverse impact of chemical insecticides.

Microbial Pesticides

Microbial pesticides are naturally occurring or genetically altered bacteria, fungi, algae, protozoans or viruses. These can be effective and used as alternatives to chemical insecticides. Microbial toxins are biological toxin material derived from microorganisms, viz. bacterium or fungus. Pathogenic effect of those microorganisms on the target pests is species specific. The effect of microbial entomopathogens occurs due to invasion through the integument or gut of the insect, which results in multiplication of the pathogen causing killing of the host, e.g. insects. The pathogens produce insecticidal toxin important in pathogenesis. Most of the toxins produced by microbial pathogens are identified as peptides, but they vary greatly in terms of structure, toxicity and specificity (Ruiu et al., 2018). The most commonly used biopesticides are living organisms, which are pathogenic for the pest of interest. These include biofungicides (Trichoderma), bioherbicides (Phytopthora) and bioinsecticides (Bacillus thuringiensis, B. sphaericus). The potential benefits to agriculture and public health programmes through the use of biopesticides are considerable. The successful use of *Bacillus thuringiensis* (Bt) and some other microbial species led to the discovery of many new microbial species and strains, and their valuable toxins and virulence factors that could be a boon for the biopesticide industry, and some of these have been translated into commercial products as well (Zafar et al., 2020; Rehmat et al 2021). These microbial pesticides offer an alternative to chemical insecticides having target specificity and ecological safe due to which that they are used either alone or in combination with other pest management programmes. 'It is an ecologically based pest control strategy which relies on natural mortality factors and control devices that disrupt these factors as little as possible.

Bacterial pesticides

Various bacterial species and subspecies, especially Bacillus, Pseudomonas, etc., have been established as microbial pesticides which control insect pest and plant diseases. The most salient among these are insecticides based on several subspecies of Bacillus thuringiensis Berliner. These include B. thuringiensis sp. kurstaki and B. thuringiensis sp. aizawai, which are highly toxic to lepidopteran larval species, and B. thuringiensis israelensis, with activity against mosquito larvae, black fly (simuliid) and fungus gnats. Other examples are B. thuringiensis tenebrionis having activity against coleopteran adults and larvae, most notably the Colorado potato beetle (Leptinotarsa decemlineata), and B. thuringiensis japonensis strain Buibui, with activity against soil-inhabiting beetles (Copping and Menn 2000). Bt produces crystalline protein that kills specific target insect pests like lepidopteran species. Bt crystalline proteins binding with gut receptor determine the target insect pest (Kumar 2012). Gray et al. (2006) reported Bt toxins (bacteriocin) produced by plant growth-promoting rhizobacteria, having insecticidal attributes. Bt is marketed the world over for the control of several important plant pests, mainly caterpillars, mosquito larvae and black flies. Commercial Bt-based products include powders containing a combination of dried spores and crystal toxins. They are applied at site of feeding of larvae on leaves or other environments. Bt toxin genes have been genetically engineered into several crops. Seed bacterization of clusterbean (Cyamopsis tetragonoloba) with Pseudomonas maltophilia controlled root rot up to 40.8% when co-inoculated with Rhizoctonia bataticola, R. solani, Fusarium oxysporum and Sclerotinia sclerotiorum under screen house conditions (Yadav et al. 2007).

Fungi

The endophytic fungi also possess the capability to induce disease resistance. Several mechanisms behind these resistances were proposed such as improved nutrient uptake, root growth, and nitrogen fixation. The decrease in the plant stress has a direct impact on the growth as well as the development of the host plants and enables them to resist the phytopathogens (Sudha et al. 2016; Bae et al. 2009). The toxic compounds produced by certain plants with endophytic colonization are reported to be effective as a pest repellent (Akello et al. 2007). The process of competition and production of biocidal compounds or phytoalexins can improve the resistance of the host plants colonized with the fungal endophytes and their molecular studies showed significant changes in the metabolism of the plant such as biochemical production which induces the mechanism of defense and resistance against the pathogen. During the endophytism certain protein that acts as pathogenicity related proteins is produced that are reported to suppress the activity of plant pathogen (Li et al. 2014). It has been evidenced by scientists from all over the world that endophyte has been proved to be an appropriate agent in this respect and due to its organic origin the products are found to be biodegradable and does not hamper the natural sustainability at all (Yadav et al. 2019a, b). So nowaday the trend has been shifted to endophytes with mycofumigating or biocontrol ability for minimizing the use of chemical insecticides or fungicides. Some endophytic genus like Muscodor albus is reported to be the storehouse of a wide and diverse range of volatile bioactive product with anti-pathogenic activity and this volatile antimicrobial producing endophyte is widely used in agricultural lands for minimizing fungal pathogen mediated crop loss or for reducing the economic loss caused by the fungal toxins during food transport or storage. Beauveria bassiana is a well-established biological control agent with a broad range of efficacy (Faria and Wraight, 2007). Furthermore, B. bassiana can colonise the soil or plants as a saprophyte or an endophyte, respectively (Boomsma et al., 2014). Consequently, B. bassiana is capable of long-term protection with minimal applications, effectively reducing insecticide application costs, and benefitting both farmers and consumers. However, to assess whether B. bassiana can be an effective and sustainable option for managing arthropod pests, it is crucial to understand its mechanisms of pathogenicity at the molecular level.

Viruses

Omnivores possess traits that make them potentially efficient pest control agents in a changing world. For example, they are more resilient to disturbances caused by biotic and abiotic factors than non-omnivorous predators (Liman et al., 2017), and can stabilize food webs depending on the type of omnivory they exhibit [11]. Omnivores can build up and maintain their populations before pest invasion, and even when prey density is very low (McLeod et al., 2021). Furthermore, zoophyte phagous omnivores (which require plant-feeding) can efficiently suppress pests not only through direct consumption, but also by inducing plant defences through plant-feeding. Omnivore plant-feeding can induce plant defences that decrease herbivore performance, and trigger production of volatiles that attract other natural enemies. To integrate phage biocontrol in IPP, the plant-pathogen-phage triangle comes into play. So far, little work has focused on the characterization of the bacterial strain diversity and the correlation between this diversity and phage infectivity. Besides collecting the optimal phage cocktail, understanding the biology of the pathogen, that is, the diversity of the pathogen, its main source of infection and its infection route in the plant, is, however, crucial to develop any targeted phage-based IPP strategy.

Insect Pheromones

Pheromones are primarily categorized into three classes viz. releaser pheromones, primer pheromones and imprinting pheromones. Releaser pheromones have an immediate and reversible response directly operated through the central nervous system, e.g. recognition, or through rapidly active neurohumoral channels, as exemplified by the milk-ejection reflex (Cross and Harris 1952). The primer pheromones have the exteroceptive response implicating the anterior pituitary gland. They make the development slow, demanding a prolonged stimulation, which consequently initiates a chain of physiological effects in the body of the recipient. The imprinting pheromones cause stimulation at a critical period of development, which may cause a permanent modification to the behavior of adults (Gonzalez-Coloma et al., 2013). The chemical composition of pheromones is highly species-specific and varies enormously among species (Symonds and Elgar 2008). For example, sex pheromones produced from female Lepidoptera are mono- or poly-olefinicacetates, alcohols, or aldehydes whereas pheromones produced by male butterflies as well as moths are aromatic compounds (such as benzyl alcohol, phenylacetaldehyde) and aggregation pheromone produced by bark beetles are mainly terpene alcohols and bicyclic ketals (Bestmann and Vostrowsky 1981). Therefore, to understand pheromones' chemical structure and role, they can be divided into some categories as discussed in below.

Plant-Based Extracts and Essential Oils

More than 2400 different plants have been documented for their pesticidal activities (**Karunamoorthi** et al., 2012). Botanical insecticides can be crude plant extracts or dried and grounded plant materials, or essential oils isolated from the plants which are used for pest management in plants (Isman et al., 2008). This protective action against pests is due to secondary metabolites produced by plants. These secondary metabolites include alkaloids, steroids, phenols, flavonoids, non-protein amino acids, quinones, tanins, terpenoids, glycosides, glucosinolates etc. Different parts of the plants such as leaves, stems, barks, flowers, fruits, seeds, cloves, rhizomes are used to prepare botanical pesticides. The mode of action of most of the plants, their extracts and essential oils are by repelling, oviposition deterrence, feeding deterrence as well as interfering with physiological activities of pests and can be toxic and lethal as well to them (Chengala et al., 2017).

Essential oils extracted from many medicinal plants have great potential to be insecticidal. Essential oils and their components extracted from plant source cause toxic effects in insects via contact, ingestion, or fumigation. Various studies have shown the insecticidal activities of the essential oils extracted from the plants belonging to Apiaceae, Asteraceae, Lamiaceae, Laureaceae, Myrtaceae and Rutaceae families. Essential oils from different plants can destroy and kill insect's species at their egg and larvae stage or at an adult stage as well as they can be antifeedant and repellent to them. Essential oils can change the feeding behavior of insects thus causing mortality and also it alters insect's behavior during oviposition and mating (Khater, 2012; Khan et al., 2021).

Insect growth regulator

A new approach to insect pest control is the use of substances that adversely affect insect growth and development. These substances are classified as "insect hormone mimics'' or "insect growth regulators'' (IGRs) owing to their effects on certain physiological regulatory processes essential to the normal development of insects or their progeny. They are quite selective in their mode of action and potentially act only on target species. The action of IGRs, however, should not be confused with other synthetic insecticides, such as organophosphates and carbamates, since these chemicals interfere with other physiological processes but do not regulate the development of normal insects. Insect growth regulators (IGRs) primarily target the immature stages of insect pests. Because IGRs elicit limited effects on nontargets, especially mammals, they are considered reduced-risk insecticides (Graf 1993). Compared with the conventional insecticides, IGRs do not exhibit quick knock-down in insects or cause mortality, but the long-term exposure to these compounds largely stops the population growth, as a result of the effects mentioned in both the parents and progeny (Mondal et al., 2000).

Biochemical pesticides

Biochemical pesticides are naturally occurring substances, for example, plant extracts, fatty acids or pheromones, controlling pests by nontoxic mechanisms. Conventional pesticides are synthetic materials that usually kill or inactivate the pest. Biochemical pesticides consist of substances that interfere with growth or mating, PGRs (plant growth regulators) or substances that repel or attract pests (pheromones). It is sometimes difficult to determine the mode of action of natural pesticides, EPA has established a committee to determine whether a pesticide meets the criteria for a biochemical pesticide (Mazid et al. 2011).

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