Biotechnology Tools in Integrated Pest Management

Subramanian Malarvannan .*[1], Palanivel Sreenithi[2].,Anbalagan Archana[3]., Suresh, M[4]. and Ramamurthy Mugesh.[5]

[1]-Associate Professor, School of Agriculture, Bharath Institute of Higher Education and Research Selaiyur, Chennai-600 073, Tamil Nadu, India
[2,3]- Third Year B.Sc. (Hons.) Ag. Students, Bharath Institute of Higher Education and Research Selaiyur, Chennai-600 073, Tamil Nadu, India
[4]-Stem Cell Laboratory, Bharath Institute of Higher Education and Research Selaiyur, Chennai-600 073, Tamil Nadu, India
[5]-Odisha University of Agriculture and Technology, Bhubaneswar-751 003, Odisha, India

Abstract

Numerous factors, such as population expansion, resource depletion, climate change, and the emergence of new pests, have a significant impact on worldwide agricultural productivity and production. Plant output can be reduced by 25–50% or even eliminated due to biotic limitations or pests. As a result, a variety of plant protection technologies have been implemented, following the trend of emphasizing the use of contemporary biotechnological instruments that have been shown to be the most efficient and essential. Because of its harmful effects on people and their animals, residual toxicity, environmental issues, pest outbreaks, and severe effects on beneficial insects, the use of chemical pesticides and other agrochemicals is being curtailed or outright outlawed worldwide. Thus, it is now essential to create a comprehensive approach to pest management in order to make it more environmentally benign, financially feasible, and socially acceptable for farmers. Limiting the use of chemicals is vital under the WTO regime in order to stay competitive and stay in the global market. The use of botanical pesticides, microbial pesticides, augmentative biocontrol by inundative releases, pheromones and attractants, and plant incorporated protectants (PIPs)/GM crops are some examples of biotechnological techniques to pest control that are covered in detail. The benefits and drawbacks of biopesticides have been discussed, along with potential future developments.

Keywords: agrochemicals, residual toxicity, pheromones, microbial pesticides

Introduction:

"Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" is what the Convention on Biological Diversity (CBD, 1992) defines as "biotechnology." According to (Lebeda *et al*., 2012), biotechnology is a group of enabling technologies that all entail the understanding and control of living things (plants and pests) or its subcellular components in order to create beneficial goods, procedures, and services. Every year, more than 20,000 different types of field and storage pests damage an estimated one-third of the world's agricultural output, which is worth many billions of dollars. Although synthetic, broad-spectrum insecticides are a good and long-term way to control pests, using chemical pesticides excessively can harm the environment, natural ecosystems, and human health. New biologically based pest management techniques that are dependable, cost-effective, environmentally friendly, and practical have been developed as a result of societal concerns about the use of pesticides. These result in the creation and registration of both naturally occurring and genetically modified bio-insecticides, such as entomopathogens (bacteria, nematodes, viruses, and fungi), plant-derived insecticides, insect hormones, and arthropod natural enemies. Bacteria (104 goods, primarily B. thuringiensis), nematodes (44 products), fungus (12 products), viruses (8 products), protozoa (6 products), and arthropod natural enemies (107 items) are among the recent global biopesticide products that have been registered.

1. Biotechnology in Plant Protection:

The use of biotechnology in plant protection can also be roughly categorized into two areas: (i) pest characterization and (ii) pest control. The initial application has significantly improved the ability to quickly and accurately diagnose pests and characterize their populations genetically. The ability to identify resistant markers for plants and DNA regions of the pests linked to resistance makes this first application an essential precondition for developing trustworthy pest management strategies. This, in turn, speeds up the breeding of cultivars with different traits. This review article focuses on the second section of the application, which covers both traditional and contemporary biotechnological pest management solutions. The latter is the current trend and includes genetic engineering and molecular breeding methods. The use of these biotechnological techniques in pest management is described in a number of reviews (Gianessi et al., 2003; Wahab, 2009; Duke 2011). Additionally, weeds, illnesses, and insect pests are covered separately in a number of reviews. Biotechnology for disease management is one of them (Fagwalawa *et al*., 2013; Shamim *et al*., 2013; Vincelli, 2016; Arya 2018; Dayou *et al*., 2018); biotechnology for insect-pest management (DeVilliers and Hoisington, 2011; Stevens *et al*., 2012; Talukdar, 2013; Jaiswal *et al*., 2018) and biotechnology for weed management (Tranel and Horvath, 2009; Duke *et al*., 2015; Westwood *et al*., 2018). The term "biotechnological approaches for crop improvement" describes the use of contemporary biotechnology methods to improve the traits and functionality of crops. Increased production, better resistance to pests and diseases, improved nutritional value, and adaptability to different environmental circumstances are only a few advantages of these techniques. RNA interference (RNAi), genome editing, tissue culture and cloning, metabolic engineering, genetic engineering, marker-assisted selection (MAS), genomic selection, and synthetic biology are some of the major biotechnology techniques used to improve crops.

1. Biotechnology for Pest Management:

Use of molecular biology techniques for the management of insect pests. The following are some strategies.

1.1 Wide hybridization: This method uses traditional breeding to transfer genes from one species to another. The resistance genes are imported from another species. For instance, Oryza sativa has acquired the WBPH resistance gene from O. officinalis.

1.2 Somaclonal variability: The variation observed in tissue culture derived progeny. E .g. Somaclonal variants of sorghum resistant to *Spodoptera litura* have been evolved.

1.3 Transgenic plants: Plants that have one or more extra genes are known as transgenic plants. This is accomplished by using genetic engineering techniques to clone more genes into the plant genome. The additional genes provide insect resistance.

1.3.1 Incorporating transgenic plants in IPM:

In order to feed the expanding global population, transgenic crops that are poisonous to herbivores and/or increase carnivore activity will be crucial. Though its application in IPM has been restricted, transgenic crops have been employed up to this point in conventional agriculture, where pests are mostly managed with pesticides.Transgenic plants have been produced by addition of one or more following

a. Bt endotoxin from *Bacillus thuringiensis*

b. Protease inhibitors

c. Amylase inhibitors

d. Lectins

e. Enzymes

a. Bt endotoxin gene: The crystal toxin known as (delta) endotoxin is produced by the gram-positive bacterium Bacillus thuringiensis. If ingested, the stomach poison endotoxin kills lepidopteran insects.
To create transgenic cotton, for example, the gene (DNA fragment) that produces endotoxin is extracted from Bt and cloned into plants like maize, cotton, potatoes, etc.

Transgenic Bt plants	**Target insect pests**
1. Cotton	Bollworms, *Spodoptera litura*
2. Maize	European corn borer
3. Rice	Leaf folder, Stem borer

4. Tobacco, Tomato	Cut worms
5. Potato, Egg plant	Colorado potato beetle

b. Protease inhibitors (PI) gene:

Proteases are digestive enzymes found in the guts of insects that aid in the breakdown of proteins. Protease inhibitors are chemicals that prevent the action of proteases and impact insect digestion. To create transgenic plants, the protease inhibitor gene is extracted from one plant and cloned into another.

e.g. transgenic apple, rice, tobacco containing PI.

e.g. Cowpea trypsin inhibitor (CpTI) is a PI isolated from cowpea and cloned into tobacco. This transgenic tobacco is resistant to *Heliothis virescens*.

c. Amylase inhibitor gene:

In insects, the digestive enzyme amylase aids in the breakdown of carbohydrates. In insects, amylase inhibitors have an impact on digesting. It has proven possible to create tomato and tobacco that are resistant to lepidopteran pests by expressing an enzyme inhibitor.

d. Lectins genes:

Proteins called lectins attach themselves to carbs. When an insect consumes lectins, it attaches itself to chitin in the midgut's peritrophic membrane, blocking nutrition absorption. For instance. The pea lectin gene in transgenic tobacco makes it resistant to H. virescens.

e. Enzyme genes:

Chitinase enzyme gene, and cholesterol oxidase gene have been cloned into plants and these show insecticidal properties.

2. Effects of transgenic crops on non-target organisms:

When thinking about using transgenic crops in IPM, it's crucial to understand how they affect non-target creatures. There are various ways to expose non-target creatures, including pollinators or carnivores, to the transgenic product. The only plants that have potential in an IPM framework are those that do not adversely affect significant non-target organisms, or at the very least, have a smaller impact than is currently shown for other management strategies.

3. Insect natural enemies as bio-control agents:

Many fundamental and practical issues that restrict the employment of insect natural enemies as biological control agents may be resolved by biotechnology. The primary goal of this insect management approach is to raise large quantities of insect natural enemies for either classical or augmentative release. Because inadvertent selection, inbreeding, genetic drift, and founder effects can result in genetic alterations, it can be challenging to maintain quality in insects raised in laboratories.

Biocontrol agents	
Parasitoids	
Trichogramma chilonis	*S. incertulas*
T. japonicum	*Cnaphalocrocis, medinalis, Pectinophora, gossypiella, Chilo infuscatellus Helicoverpa armigera* and other lepidopteran pests
Goniozus nephantidis	Coconut black headed caterpillars
Trichospilus pupivora	Coconut black headed caterpillars
Bracon breviconis	Coconut black headed caterpillars
Predators	
Cryptolaemus montrouzieri	Mealy bugs
Crysoperla carnea	Soft bodied insects

Organism	**Targetpests**
Virus	
Nuclear Polyhedrosis Virus	*Helicoverpa armigera, Spodoptera litura*
Granulosis virus	*Helicoverpa armigera*
Bacteria	
Bacillus thuringiensis	*Helicoverpa armigera*
Fungi	
Beauveria bassiana	Lepidopteran and Coleopteran pests
Metarhizium anisopliae	Lepidopteran and Coleopteran pests, soft-bodied insects like Scales Aphids and Thrips
Verticillium lecanii	Soft-bodied insects like Scales Aphids and Thrips
Paecilomyces fumosoroseus	Whiteflies on cotton, mites
Disease control	
Bacteria	
Pseudomonas fluorescens	Sheath blight in rice, Root rot disease in sugarcane Foot rot and slow decline in black pepper, Capsule rot and clump rot in cardamom, Rhizome rot in ginger and turmeric, Fusarial wilt in coriander, Leaf spot in cucumber, Psudostem and leaf spot in banana
Fungi	
Trichoderma viride	Quick wilt, Slow wilt, Leaf blight, Anthrocanose, stem rot and root wilt in black pepper, fungal diseases of Cardamom, Ginger and Turmeric
	Nematode control
Bacteria	
P. fluorescens	Inhibits early root penetration of cyst nematode in sugar beet
Fungus	
Paecilomyces lilacinus	*Meloidogyne* spp., *R. similis* and *Heterodera* spp.
Myrothecium sp.	*Meloidogyne* spp., *R. similis* and *Heterodera* spp.

Pheromones and attractants in pests management:

In pest management, pheromones are used to interrupt mating by dosing the crop with the right pheromone, which stops male moths from finding "calling females" and suppresses mating. The idea is to create slow-release formulations that interfere with mating by maintaining a comparatively high pheromone concentration for a number of weeks. Early detection of the pest's presence is facilitated by using species-specific pheromones to trap the male moths of the target pest species. Determining the dynamics of moth populations over crop seasons aids in the development of pest management plans and the justification or scheduling of pesticide use.

Pheromones	Insect species
Species specific sex pheromones	*Helicoverpa armigera, Spodoptera litura, Earias vitella, Rhynchophorus ferrugineus, Pectinophora gossypiella, Cnaphalocrocis medinalis, Scirpophaga incertulus*
Methyl eugenol	Fruit flies- *Bactrocera spp.*
Cuelure	Cucurbit fruit flies- *S. cucurbitae*

4. **Entomopathogens**:

Worldwide, entomopathogens make up a significant portion of biological insecticides. Asian nations have acknowledged the need for biological insecticides, with entomopathogens receiving the greatest attention, due to two phenomena: the pervasive resistance to synthetic pesticides and the intolerable side effects. For example, entomopathogens—which include bacteria, viruses, nematodes, and fungi—make up nearly all of Thailand's imported biological pesticides. Thailand's biopesticide market is dominated by Bt, but fungus has lately begun to play a bigger role in integrated insect management programs and is predicted to grow its market share. China, Vietnam, and Thailand are currently making efforts to produce Bt, nematodes, and nucleopolyhedrovirus locally. Therefore, it is predicted that microbial insecticides would expand at a faster rate than chemical insecticides over the next ten years. In order to improve the market share for microbial insecticide products, this study will emphasize the main obstacles limiting the usage of those entomopathogens and investigate the extent to which contemporary biotechnological procedures may overcome these limits.

4.1 **Entomopathogenic fungi:**

5. Few entomopathogenic fungal species have been given substantial consideration as possible commercial possibilities, despite the fact that over 750 species have been documented to infect insects. Hirsutella thompsonii, the first mycoinsecticide to be registered, has been shown to generate significant epizootics in spider mites. Verticillium lecanii and Paecilomyces fumosoroseus are the next mycoinsecticides. They were recently registered to control spider mites, aphids, thrips, and whiteflies. Beauveria bassiana and Metarhizium anisopliae are insect fungus that have a considerably wider host range. They are efficient against both coleopteran and lepidopteran field insects as well as homopteran and lepidopteran greenhouse insects (Flexner and Belnavis, 1998). Lack of understanding of the molecular and metabolic underpinnings of fungal pathogenesis and the lack of an effective cloning technology for species other than deuteromycete fungi limit the potential of genetic engineering to optimize entomopathogenic fungi. The molecular and metabolic underpinnings of M. anisopliae's pathogenicity, which results in green muscardine illnesses, have been thoroughly investigated, particularly with regard to the fungus's ability to penetrate host cuticles.

RNA Interference (RNAi) for Pest control:

Double-stranded RNA (dsRNA) is inserted into a cell using a process called RNA interference to inhibit undesirable genes and, occasionally, the creation of new genes (Silver et al., 2021). The use of RNAi gene-editing techniques for gene silencing into crop protection and pest control initiatives has been the subject of extensive research in recent years. By carefully targeting the genes required for the pest insect's development, growth, and reproduction, RNA interference (RNAi) is utilized to remove pest insects without harming non-target species (Mamta and Rajam, 2017; Munawar et al., 2023). Numerous insects are regulated by RNAi, a naturally occurring cellular defense mechanism mediated by double-stranded RNA (dsRNA). This is particularly true for insects that feed on sap. However, this insect population is uncontrollable by transgenic crops (Kunte et al., 2020; Chung et al., 2021). Since gene silencing only impacts cells that are affected, the delivery method is essential to achieving this effect. Furthermore, additional material is required for delivery, and it is difficult to determine the amount of dsRNA consumed by insects following oral treatment (Lin et al., 2017; Kunte et al., 2020). The soaking method, which entails immersing the insects in a dsRNA-containing solution, works best with specific insect species and developmental stages that have a high rate of dsRNA absorption from the solution (Kunte *et al*., 2020; Nitnavare *et al*., 2021). Target genes in several insect orders have been effectively repressed by RNA interference (RNAi) technology; nevertheless, because of the present research gap, this strategy is less practical as a long-term method of reducing insect pests (Jain *et al*., 2021).

6. Microbial pesticides:

Potential biological alternatives in eco-friendly agriculture include beneficial and environmentally friendly fungus, bacteria, viruses, and protozoa that can destroy some disease-causing germs, nematodes, and insect pests while simultaneously encouraging plant development. White grub, stalk borer, sugarcane black bug, and other lepidopteran pests have been successfully controlled with entomopathogenic viruses, bacteria, fungi, and protozoa. Similarly, bacteria like Bacillus thuringiensis have gained popularity in managing Plutella and Helicoverpa, while viral pathogens like NPV and GV are also effective in controlling Spilosoma, Amsacta, Spodoptera, Helicoverpa, etc. Many bacterial and fungal plant diseases are controlled by using bacteria like Pseudomonas and fungus like Trichoderma (Ramarethinam *et al*, 2003). These organisms use mycoparasitism or the synthesis of antibiotics to inhibit the growth of harmful bacteria and fungi. Potential nematode control agents for parasitic nematodes in a variety of crops include the use of nematophagous fungi and bacteria, specifically P. lilacinus and P. fluorescens.

Development of resistance:

6.1 Development of resistance in insect pests:

Populations of insect pests have demonstrated an amazing ability to become resistant to chemical insecticides. According to Moberg (1990), more than 500 insect species have become resistant to pesticides. As a result, there are worries that the use of transgenics will cause insect populations to become resistant. Some of these worries might be legitimate, while others appear wildly inflated. Since the toxins are expressed in every part of the plant, the majority of transgenic plants created to date have Bt genes controlled by the constitutive promoter of the cauliflower mosaic virus (CaMV35S). This technique may cause the target insects to acquire resistance. But in recent years, a number of site- or tissue-specific promoters have been created. Over the course of the crop-growing season, toxin production may also decline, which could result in the development of resistance to the toxin in question as well as to other similar Bt toxins to which insect populations may initially be very susceptible. The most susceptible members of a community are eliminated by low dosages of the toxins, leaving a population where resistance can form somewhat more quickly. Because the majority of Bt toxins work similarly, resistance to one toxin can potentially result in the development of cross-resistance to other toxins. Insects that have been modified to be resistant to one Bt toxin may not be immune to other Bt toxins, according to some research (Sharma and Ortiz, 2000).

6.2 Development of resistance to antibiotic genes:

7. The evolution of resistance in human infections may result from the use of antibiotic genes as a marker to select for gene transfer. However, the majority of scientists believe that there is very little chance of undermining the medicinal effectiveness of antibiotics through transgenic plants. Antibiotic resistance genes might theoretically spread from a crop to environmental microorganisms. Antibiotic resistance genes may spread to disease-causing bacteria because bacteria are good at exchanging genes. Laboratory experiments have shown that genes may be transferred from plants to microbes, and this may have occurred during evolution (Doolittle, 1999). There is a slight possibility that such a transfer might take place, according to a number of studies, but whether or not the commercial cultivars should have this gene is still up for debate. Techniques for eliminating selectable marker genes following transgenic selection have been developed.

Artificial Intelligence (AI) in pest management:

7.1 Future Prospects:

Rashwin et al. (2023) assert that the instruments used to address pest problems change along with agriculture and its related industries. This transformation is being led by new biotechnological instruments. Known as "genetic scissors," cutting-edge methods like CRISPR-Cas12 and CRISPR-Cas13 increase the accuracy of genetic alterations and enable targeted interventions in pest genomes. These methods allow scientists to alter particular genes in pests, making them susceptible or even sterile. This accuracy improves the safety and precision of genetic alterations by reducing off-target effects. Nanotechnology is also being used in the control of pests. Biopesticides can be encapsulated in nanoparticles to prevent degradation and guarantee targeted insect delivery. Precision at the nanoscale increases the effectiveness of biopesticides while reducing their negative effects on the environment. Artificial intelligence (AI) and data analytics play a key role in transforming pest management techniques in the age of digital transformation by improving their accuracy and proactivity. Smart insect traps are also made possible by AI (Rosado et al., 2022). These traps minimize collateral damage to non-target creatures by accurately recognizing target pests, allowing the selective deployment of pheromones or biopesticides.

8. Public acceptance of biotechnology products:

Despite the vast advantages of using genetic engineering and modern biotechnology in agriculture, there are still scientific and public concerns in many parts of the world regarding the food safety and environmental effects of genetically modified crops, as well as socioeconomic problems related to the use and accessibility of modern biotechnology products (Mbabazi et al., 2016). Misperceptions, myths, misunderstandings, poor communication, and fear of GE technology have all resulted from a lack of knowledge and awareness. Along the product development value chain, timely access to high-quality, scientifically based information is essential for stakeholders (scientists, policy makers, regulators, lawyers, farmers, journalists, extension workers, consumer groups, NGOs, religious groups, etc.) to make well-informed decisions about the use and applications of biotechnology. Different stakeholders require different types of information via reliable and suitable communication mechanisms. For GE products to be more widely accepted, it is crucial that all stakeholders get education.

Advantages of Biotechnology in IPM:

i) Target-Specific Action:

Certain pests are targeted using biotech techniques, such as genetically modified (GM) crops (like Bt cotton), which do not harm beneficial insects.

ii) Reduced Chemical Pesticide Use:

By reducing the demand for synthetic pesticides, genetically modified crops or biopesticides lessen the dangers to human health and the environment.

iii) Early Detection and Monitoring:

Rapid and precise pest detection is made possible by molecular technologies, which aid in prompt response.

iv) Environmentally Friendly:

Compared to conventional chemicals, biological control agents—such as bacteria, fungus, or viruses—are more environmentally benign.

v) Resistance Management:

Through gene monitoring and the strategic use of resistant crop types, biotechnology aids in the tracking and management of pesticide resistance.

vi) Improved Crop Yields and Farmer Profitability:

Higher yields and cheaper costs are frequently the outcome of less pest pressure and fewer chemical applications.

Disadvantages of Biotechnology in IPM:

i) Development of Resistance:

Long-term efficacy may be diminished if pests become resistant to GM crops (such as Bt resistance).

ii) Cost and Accessibility:

Smallholder farmers may find biotech solutions costly and less accessible, particularly in emerging nations.

iii) Environmental Concerns:

possible unforeseen consequences for biodiversity and non-target creatures.

iv) Regulatory and Ethical Issues:

Because of ethical or safety issues, GM crops and biotech interventions may be subject to stringent laws and public opposition.

v) Dependency on Few Technologies:
The agro-ecosystem's resilience and biodiversity may be diminished by an over-reliance on specific biotech techniques.

vi) Lack of Awareness and Training:

It's possible that farmers lack the expertise necessary to correctly incorporate biotech tools into IPM efforts.

Discussion and Conclusion:

Since produce farmed without the use of pesticides and fertilizers is the most sought-after and sells for a premium price, farmers are actually showing interest in organic farming these days. Now that certification bodies have been found, the farms and their produce are being certified by them. Even if biotechnology methods are not widely used because of the aforementioned limitations, they will probably have an impact on crop protection in the nation in the near future, resulting in an environment that is safer. The key to evaluating biotechnology's potential to boost agricultural output and support the sustainability of agricultural systems is knowledge and ongoing research. Examples of the application of biotechnology that results in sustainable control methods include the possible development of bio-control agents that involve beneficial insects and microorganisms that coexist peacefully with genetically modified plants. Public concerns on extensive use of chemical insecticides, insect resistance development, and the rising cost of developing new synthetic insecticides, all suggest that integrated insect pest management utilizing biological control products will become increasingly important in the years to come. Even while biotechnology has greatly improved the management of insect pests, there are still several unanswered problems, particularly in Asian nations where biotechnology has the potential to be most lucrative. The technology's uncertainty regarding successful research and end-user adoption, high startup costs, public awareness and acceptance, national policies on biosafety and intellectual property issues, technology dissemination and proper implementation, institutional and human resource development, and limited funding due to the long-term and ongoing nature of the research are some specific examples. To improve public awareness of the hazards and advantages of applying biotechnology, responsible national institutions and other linked research organizations should conduct educational and training initiatives.

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