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A Review of the Present and Prospective Status of Biopesticides as Potential Substitutes for Chemical Pesticides

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Abstract

Chemical pesticides, which are employed in agricultural fields to limit the damage caused by pests and diseases, represent several long-term dangers and threats to living things. Biopesticides are currently used in a variety of agricultural and horticultural settings, including organic farming, integrated pest management systems, and conventional farming. Despite their potential benefits, there are several barriers to the widespread adoption of biopesticides. In this review, we will focus on the current challenges and future prospects of the use of chemical pesticide in pest management.

Keywords- Biopesticide, pest management, chemical pesticides, Agriculture

1. Introduction

Synthetic chemicals like nematicides, herbicides, algicides, miticides, bactericides, fumigants, termiticides, repellents, insecticides, molluscicides, and pheromones have been utilized to enhance agricultural productivity throughout history. However, the drawbacks linked to the application of these conventional pesticides encompass pest resistance and ecological degradation.Because of their negative side effects, chemical pesticides, which are employed in agricultural fields to limit the damage caused by pests and diseases, represent several long-term dangers and threats to living things. They have been linked to malignancies (Nicolopoulou-Stamati et al., 2016), birth defects (Kalafati et al., 2018),and long environmental half-lives (Kallioraet al., 2002) due to their nonbiodegradable nature. Furthermore, these synthetic pesticides are widely used and have a big influence on product manufacturing due to their powerful inhibitory activity against pests and prospective applications (Liu et al., 2021). As a result, regulations limiting their use in commercial farming are

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causing a 2% annual decrease in the use of synthetic pesticides and a 10% increase in the use of biopesticides as substitute agrochemicals (Damalas and Koutroubas, 2018).Still, the lack of products to suit farmers' requests, the expensive price of refined products, and the generally moderate action of biopesticides prevent their full adoption (Verma et al., 2021).

However, these disadvantages are outweighed by the biopesticides' minimal, if any, toxicity. In addition, they are biodegradable, selective (meaning they don't affect non-target organisms), and capable of addressing pest resistance problems brought on by synthetic pesticides (Mishra et al., 2020).

2.The Current Status of Chemical Pesticides

Chemical pesticides have been used for many decades and have played a crucial role in increasing agricultural productivity and preventing food shortages. However, their widespread use has also led to some unintended consequences. Chemical pesticides can contaminate the environment, affecting non-target organisms and polluting soil and water sources. They can also harm human health through direct exposure or consumption of contaminated food products. Moreover, pests have the ability to acquire resistance against chemical pesticides, necessitating the application of increased dosages or stronger chemicals. Consequently, this can result in additional harm to the environment. In the context of India, nearly 30% of agricultural yield is compromised due to the invasion of pests and the utilization of pesticides to safeguard crops (Bhadbhade, 2002). The residues of pesticides have been discovered to pose a threat to both human health and the environment, in addition to the pesticides themselves. There are reports showing that worldwide overexposure to pesticides resulted in $43x10^6$ cases of pesticide poisoning annually, unnecessary pesticide use has also created global problems like pest resistance, resurgence and pesticide residues in crops and soil (Qiao, 2003).

3.The advantages of Biopesticides

Biopesticides offer several advantages over chemical pesticides. First, they are generally less harmful to the environment and non-target organisms. They are also less persistent in the environment, reducing the risk of long-term contamination. Biopesticides are also less likely to cause resistance in pests, as they typically have multiple modes of action. Additionally, biopesticides are often specific to certain pests, reducing the risk of harm to beneficial insects and other organisms.The extensive application of routine pesticides in large-scale agriculture over an extended period, especially during the Green Revolution era, has resulted in various issues. These include pesticide-related pollution, the use of chemicals after harvesting leading to bioaccumulation, loss of biodiversity, and the emergence of secondary pests while eliminating natural and beneficial enemies.These negative results are not related with the utilize of biopesticides. Hence, restrictive confinements are ceaselessly forced on engineered pesticides to diminish their numbers with time. For occasion, there has been a lessening to 250 dynamic fixings of ordinary pesticides in 2009 as contradicted to more than 1,000 in 2001 whereas entrance of modern routine pesticides into the showcase diminished from 70 in 2000 to 28 in 2012(McDougall, 2013).

4.Classification of Biopesticides

There are three main types of biopesticides: microbial, plant-incorporated protectants (PIPs), and biochemical. Microbial biopesticides are made from microorganisms such as bacteria, fungi, and viruses that can control pests by infecting or poisoning them. Genetically modified crops known as PIPs have been engineered to produce pesticides internally, offering inherent defense against pests. Biochemicals

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, on the other hand, are substances derived from natural sources such as plants, animals, or minerals, and are utilized as pesticides. The effectiveness of most biopesticides is attributed to chemical interactions with the targeted pests. Fungi-based biopesticides are utilized for weed management, beneficial bacterial pesticides are employed for controlling fungal and bacterial infections, and viral pesticides are harnessed to combat insect infestations (Hubbard et al., 2014). The pest like fungi can infect the plants through their stomata or microspores in the leaf epidermis (Baarlen et al., 2007). A coherent plan is still required that ensures proper development of biopesticides and bio-inoculants to maximize their outcome, effectiveness, stability and delivery (Hynes and Boyetchko 2006). Moreover, active substances must account for the evolution of resistance that emerges during pesticide use. Biopesticides, such as spores of entomopathogenic fungi, have been shown to lead to substantial mortality of 7-14 days following exposure (Blanford et al., 2011).

5.Current Use and Effectiveness of Biopesticides

Biopesticides are utilized across various agricultural and horticultural settings, which include organic farming, integrated pest management systems, and conventional farming. Microbial biopesticides, like Bacillus thuringiensis (BT) and Beauveria bassiana, are commonly employed for insect pest control. *Trichoderma viride*, *Metarrhizium*, *Beauveria bassiana*, and nuclear polyhedrosis virus are currently being used to safeguard plants (Rao et al., 2007). Additionally, biochemicals such as neem oil and pyrethrin are utilized as pesticides to combat a wide range of pests. These biopesticides are classified into (a) microbial biopesticides containing microorganisms that control diseases and insects, (b) botanical biopesticides derived from plants, and (c) plant incorporated protectants. Over the past few decades, biopesticides have emerged as the preferred alternative to chemical and synthetic pesticides for pest management (Kour et al., 2020).The effectiveness of biopesticides varies depending on the type of pest, the environment, and the specific product used. In some cases, biopesticides have been shown to be just as effective as or even more effective than chemical pesticides. In the case of the European corn borer, Bacillus thuringiensis corn has proven to be remarkably efficient in combating this significant corn crop pest. Nevertheless, there are instances where biopesticides may not exhibit the same level of effectiveness as chemical pesticides, necessitating multiple applications for achieving the desired control. A noteworthy substitute for synthetic chemical insecticides in safeguarding crops can be found in vegetable oils, (Rongai et al. 2008). The mode of action of biopesticides is specific and operates by targeting pests. Nowadays, biopesticides have been played a vital role in the agro-market and are widely utilised in organic farming (Seiber et al., 2014; Nawaz et al., 2016; Lengai and Muthomi, 2018).

Table 1: Bioinsecticides available in India.

Biocontrol Agents	**Product Name**	**Against Pests**
Bacillus thuringiensis subsp. Israelensis	Tacibio/Technar	Leipdopterous pests
B. thuringiensis subsp. Kurstaki	Bio-Bart/ Biolep/Halt/Taciobio-Btk	Lepidopterous pests
Baeuveriabassiana	MycoJaal/Biosoft/ATEC/Baeuveria/LarvoGuard/Biorin/Biolarvex/Phalada101B/Biogrubex/Biowonder/Veera/Bioguard/B io-power	Coffee-berry borer, diamondback moth, thrips, grasshoppers, whiteflies, aphids, coding moth
Helicoverpaarmigera NPV	Helicide/Helocide/Biovirus-H/Heligard/VirinH	Cotton bollworm
Metarhizium anisopliae	ABTEC/Verticillium/Meta-Guard/Biomet/ Biomagic/Meta/Biomet/Sun Agro Meta/BioMagic	Coleoptera and lepidoptera, termites, mosquitoes, leafhoppers, beetles, grubs

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Pseudomonas fumosoroseus	Nemato-Guard	Whitefly
Pseudomonas lilacinus	Yorker/ABTEC/Paceilomyces/Paecil/Pacihit/ROM biomite/Bio-Nematon	Whitefly
Verticillium lecanii	Verisoft/Verticillium/VertGuard/Bioline/Biosappex/Versitile/Ecocil/Phal ada 107 V/Biovert Rich/ROM Verlac/ROM Gurbkill/Sun AgroVerti/Bio-Catch	Whitefly, green coffee bug, homopteran pests
Spodoptera litura NPV	Spodocide/Spodoterin/Spodi-cide/Biovirus-S	Spodoptera litura

Source- Modified from Mishra et al. (2015)

Commercially, there are some biopesticides available to farmers. Commonly used biopesticides are living organisms, which have pathogenic potential against pests. These consist of bioinsecticides (*Bacillus thuringiensis*) (Table 1), biofungicides (Trichoderma) (Table 2), and bioherbicides (Phytopthora) (Table 3).

Table 2: Some biofungicides developed and commercialized around the world.

Biocontrol Agent	**Product Name**	**Target Pathogen**	**Crop**
Agrobacterium radiobacter K84	GALLTROL	*Agrobacterium tumefaciens*	Ornamental nursery stock, soil treatment
*Bacillus subtillis*QST 713	CEASE	*Rhizoctonia solani, Pythium, Phythophora, Fusarium*	Most greenhouse ornamentals and vegetable transplants
*Bacillus subtilis*GB03	COMPANION (LIQUID)	Leaf spots, Powdery mildew, Botrytis, bacterial diseases, *Rhizoctonia solani, Pythium, Phytophthora*	Most greenhouse ornamentals and vegetable transplants
Bacillus subtilis	EPIC (Dry powder).	*Fusarium spp., Rhizoctonia solani, Alternaria spp., Aspergillus spp.*	Cotton and legumes
Bacillus subtilis	KODIAK, KODIAK HB, KODIAK A.T (Dry powder)	*Rhizoctonia solani, Alternaria spp., Aspergillus spp., Fusarium spp.*	Cotton and legumes
Coniothryiumminitans	CONTANS WG	*Sclerotinia sclerotiorum, S. minor*	Most greenhouse ornamentals, vegetable transplants, herbs, Soil treatment
Gliocladium virens GL-21	SOIL GARD	*Rhizoctonia solani, Phytium*	Most greenhouse ornamentals, vegetable transplants
Gliocladiumcatenulatum JII-446	PRESTOP WP	*Botrytis, Rhizoctonia solani, Pythium spp., Phytophthora, Fusarium, Verticillium spp.*	Most greenhouse ornamentals, vegetable transplants
Fusarium oxysporum (nonpathogenic)	FUSACLEAN (spores)	Fusarium oxysporum	Asparagus, basil, carnation, tomato

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Myrothecium verrucaria	DITERA (Wettable powder)	Root knot, citrus cyst, stubby root, lesions and burrowing nematodes	Fruit vegetables and ornamental crops, turf
Pseudomonas cepacian	INTERCEPT	*Fusarium spp., Rhizoactoniasolani, Pythium*	Maize, vegetables, cotton
Reynoutriasachalinensis	REGALIA	*Botrytis, Leaf Spots, Powdery mildew, bacterial diseases, Fusarium, Rhizoctonia, Pythium, Phytophthora, Verticillium*	Herbs and spices, soil treatment, plant health promoter
Streptomyces griseovirdis	MYCOSTOP (Dry powder)	*Botrytis, Rhizoctonia, Pythium, Phythophora, Alternaria*	Most greenhouse ornamentals, vegetable transplants
Streptomyces lydicus	ACTINOVATE	Powdery mildew, Downy mildew, *Botrytis, Rhizoctonia, Pythium, Phytophthora*	Most greenhouse ornamentals, vegetable transplants
Trichoderma harzianum	PLANT SHIELD, ROOT SHIELD, T-22 PLANTER BOX	*Cylindrocladium, Fusarium, Rhizoctonia, Pythium,Thielaviopis*	Most greenhouse ornamentals, vegetable transplants

Source- Modified from Burges (1998), and Aneja et al. (2016).

Table 3: Some commercial bioherbicides are available and used globally.

Biocontrol Agents	**Product Name**	**Formulation Type**	**Target Weed**	**Year of Registration and Country**
Puccinia thlaspeos	WOAD WARROIR	Powder	Isastis tinctoria (dyer's wood or glastrum) in farms and rangeland	2002 USA
Chondrostereum purpureum	MYCOTECH^{TM} PASTE	Paste	Deciduous tree species	2002/2005 Canada
Alternaria destruens	SMOLDER^{R}	Conidial suspension	Dodder species	2005 USA
Sclerotinia minor	SARRITOR	Granular	Dandelions in lawns/turf	2007 Canada
Fusarium oxysporum f. sp. Stigae	STRIGA	Solid, Dried Chlamydospores+ Arabic gum	*Striga hermonthica& S. asiatica*	2008 Africa
Tobacco mild green mosaic virus	SOLVINIXTM	Wettable powder/ Foliar spray suspension	Soda apple (Solanum viarum)	2009 Florida
Lactobacillus spp. Lactococcus spp.	ORGANO-SOL	Liquid	Broadleaved weeds	2010 Canada
Streptomyces spp.	MBI-005 EP	Emulsified/Aque	Broadleaved weeds	2012 USA

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		ous suspension		
Gibbagotrianthe mae	GIBBATRIAN TH	Liquid Conidial Suspension+ Surfactant	*Trianthemaportulacastrum*(Horse purslane)	2014 India

Source: Modified from Aneja, 2014.

6. Barriers to Widespread Adoption of Biopesticides

Although biopesticides offer various advantages, numerous obstacles hinder their widespread implementation.

6.1. Lack of Awareness and Education

A significant obstacle hindering the extensive implementation of biopesticides is the insufficient knowledge and education among farmers and other relevant parties. Numerous farmers remain unaware of the existence of biopesticides and the potential advantages they offer. Consequently, they persist in relying on conventional chemical pesticides, which they are more acquainted with. Furthermore, there is a dearth of education and training regarding the appropriate utilization and application of biopesticides.

6.2. Limited Availability and Accessibility

Another significant barrier to the widespread adoption of biopesticides is their limited availability and accessibility. Unlike chemical pesticides, which are widely available in the market, biopesticides are not as easily accessible. They are often not stocked in local agro-input shops, and farmers may have to travel long distances to purchase them. This limited availability and accessibility make it challenging for farmers to switch to biopesticides, even if they are interested in doing so.

6.3. High Cost

The widespread adoption of biopesticides is hindered by the considerable cost associated with them. In comparison to chemical pesticides, biopesticides are generally more expensive, rendering them unaffordable for small-scale farmers who have limited resources at their disposal. The elevated cost of biopesticides can be attributed to the intricate and costly production processes involved, as well as the absence of economies of scale. As a result, many farmers opt for cheaper chemical pesticides, even though they are aware of the potential risks associated with their use.

6.4. Lack of Government Support

Government support and policies are essential in facilitating the acceptance of biopesticides. Nevertheless, numerous countries face a dearth of government backing for the utilization of biopesticides. Government policies frequently exhibit a preference for chemical pesticides, while simultaneously failing to provide adequate incentives for farmers to transition to biopesticides. Consequently, this lack of government support impedes the widespread adoption of biopesticides, rendering them less appealing to farmers.

6.5. Resistance to Change

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Farmers are often resistant to change, especially when it comes to trying out new methods or products. Many farmers have been using chemical pesticides for decades and are accustomed to their use. They may be hesitant to switch to biopesticides, as it would require them to change their farming practices and adapt to a new way of pest management. This resistance to change is a significant barrier to the widespread adoption of biopesticides.

7. The Future Potential of Biopesticides

Despite the current challenges, the future looks promising for biopesticides. Additionally, there is a growing trend towards organic and sustainable agriculture, which will drive the demand for biopesticides.The global market for biopesticides has been steadily growing in recent years, and this trend is expected to continue in the future. The rise in consumer demand for organic food and sustainable agricultural methods has significantly propelled the expansion of the biopesticides industry. As consumers become increasingly conscious of the health hazards linked to chemical pesticides, they are actively pursuing safer options. Furthermore, governmental regulations and initiatives that advocate for the adoption of biopesticides are further fueling the market's growth. As well as advancements in biotechnology have also played a significant role in the development of new and improved biopesticides. Scientists are now able to genetically modify microorganisms to produce toxins that target specific pests. This has led to the development of highly effective and specific biopesticides that can control pests without harming beneficial insects or the environment.Additionally, crop rotation and cultural practices—two IPM strategies—can be used in conjunction with biopesticides. This integrated approach can support a more environmentally friendly and sustainable approach to pest management by reducing the need for chemical pesticides. There have been reports that IPM is a cost-effective method that lowers crop yield loss (Hagstrum and Flinn, 2018). Currently, the adoption of IPM is limited owing to several factors, which include awareness, user preference, production industry, technology, policy, and culture (Deguine et al., 2021). An important part of management programs remains the protection of grains and choices for storing them. Without grain protectants, serious economic consequences would ensue, particularly in industries with narrow profit margins. A promising change in management will be from chemical-based pest management to IPM using computer-based decision support systems (Arthur, 1996).The integration of biopesticides into agricultural practices necessitates a more comprehensive comprehension of their action mechanisms in order to broaden their effectiveness against pests, enhance their performance in the field, develop more efficient delivery systems, extend their shelf life, reduce production costs, ensure easy accessibility, increase awareness among farmers, and establish straightforward registration and regulation policies (Fig.1).

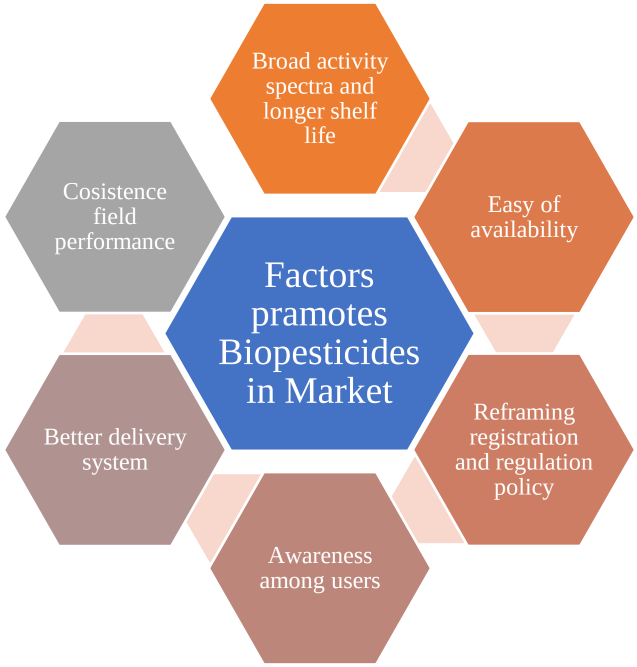

Fig.1 Factors that contribute to the expansion of the Biopesticide market.

8. Conclusion

In conclusion, biopesticides have the potential to be a viable substitute for chemical pesticides in the future. They offer several benefits, including reduced environmental impact, less risk of resistance, and greater specificity to pests. However, there are still challenges that need to be addressed, such as cost and resistance from farmers and consumers. With continued research and development, biopesticides have a promising future in pest management and can contribute to a more sustainable and environmental friendly in agricultural industry.

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