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Biopesticides for Climate Resilient Agriculture: General Scenario in India

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ABSTRACT

Climate change is a global problem that requires long-term commitment and action from all stakeholders of society. Climate resilience requires generation of new products, development of some already available products and/or others products that not yet developed to improve the living standards and offering higher quality of life and thus transforming the economy and value chains. According to scientific data, the use of synthetic pesticides in contemporary industrial agriculture greatly increases greenhouse gas emissions and increases the susceptibility of our agricultural systems to the consequences of climate change. A more effective and environmentally friendly method of protecting plants from plant diseases was required due to the negative impacts of synthetic pesticides. Utilizing biopesticides in conjunction with synthetic pesticides through the Integrated Pest Management (IPM) approach yields positive outcomes for the environment and economy. The efficacy of biopesticides would be greatly increased by more research into the mechanisms that extend their stability and shelf life. The extensive use of biopesticides can help to achieve the objectives of natural farming, which include restoring soil health, maintaining diversity, guaranteeing animal welfare, highlighting the efficient use of natural and local resources, and promoting ecological justice. In this article the advantages of biopesticides over synthetic pesticides have been discussed for the climate resilient society and sustainable agriculture in India's perspective.

Keywords Biopesticides, Synthetic pesticides, Integrated pest management, Climate change.

INTRODUCTION

Climate change is one of the greatest challenges (Hewitt *et al.* 2020) facing humanity today. Climate change is a global problem that requires long-term commitment and action from all segments of the society. Adapting to climate change which is also known as climate resilience (Singh and Chudasama 2021) requires a whole generation of new products, some already available and others not yet developed, as well as services that will contribute to improving living standards and offering higher quality than their predecessors, thus transforming the economy and value chains. Scientific evidence shows that in modern industrial agriculture, the use of synthetic pesticides (Curl *et al.* 2020, Shah 2020) contributes significantly to greenhouse gas emissions

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(US EPA 2022) and also makes our agricultural systems more vulnerable to the effects of climate change. Pesticides contribute (Drugmand *et al.* 2022) to climate change throughout their entire life cycle, through production, packaging, transportation, application and even environmental degradation and disposal.

The use of food produced with organic and safe plant protection (Letourneau and Van Bruggen 2006, Stoleru and Sellitto 2016, El-Shafie 2019) products is currently receiving attention on a global scale. Some synthetic pesticides are no longer used in agricultural production as a result of the discovery of dangerous synthetic pesticide residues in food and growing awareness of food safety, while biopesticides (Rodgers 1993, Fenibo *et al.* 2022) are becoming more and more common in organic farming. Adoption of biopesticides leads to sustainable agriculture (Reganold *et al.* 1990, Harwood 2020) and a healthy environment, while continuous use of synthetic pesticides pollutes the ecosystem. Because of the harmful effects of using synthetic pesticides, a more efficient and environmentally acceptable way to protect plants against plant diseases was highly needed. In this study the advantages of biopesticides over synthetic pesticides have been summerized and more emphasis has been given on the future of biopesticides on India's perspective.

Synthetic pesticides

Pesticide (WHO 2020) generally destroy, resist or control pests in any form. Sulfur compounds (Umetsu and Shirai 2020) used by Sumerians to control insects and mites is the first recorded use of pesticides. The evolution (Georghiou 1972) of pesticides occurs in different phases by using early pest management, using plant, animal or mineral derivatives, using inorganic products and industrial by-products, using synthetic organic compounds. But the industrial pesticide production was boosted after the World War II when organic compounds was introduced as pesticides. For e.g. insecticides properties of organochloride compounds, such as BHC and DDT were discovered and exploited after late 1930s. Similarly properties as an insecticide of BHC (Benzene hexachloride) was identified after 1944, though the compound was produced in long back. Müller's award of the Nobel Prize (The Nobel Prize 1948) in 1948 for discovering the insecticides properties of DDT (dichlorodiphenyl trichloroethane). Synthetic pesticides use is directly associated with human health impacts (Rasool *et al*. 2022) and the degradation of ecosystem services such as clean air, water and healthy soil (Tudi *et al*. 2021).

Health impacts of synthetic pesticides

During the Green Revolution, intensive use of synthetic pesticides was common in commercial agriculture to increase agricultural productivity to meet the world's food demand. In addition to this, the use of synthetic pesticides had adverse effects on the environment and its ecological receptors, including human health (Tudi *et al.* 202, Rasool *et al.* 2022). Exposure to dangerous pesticides can cause acute illnesses such as skin rashes, gastrointestinal and respiratory illnesses and central nervous system problems. Additionally, pesticide exposure has been linked to a number of chronic diseases, including cancer, reproductive and developmental disorders, and long-term neurological dysfunction. Agricultural workers, residents of rural areas, and residents of areas where pesticides are produced and pesticide waste is dumped are highly affected.

Climate change and synthetic pesticides

Synthetic pesticides are one of the main causes of the global decline in biodiversity. They severely harm pollinators (Reshi *et al.* 2025) such as honeybees. Earthworms and other soil invertebrates (Gunstone *et al.* 2021) can be killed by the use of insecticides and other pesticides. Soil invertebrates play an important role in aerating, structuring, and preventing soil compaction so that soil can retain water and perform other beneficial roles. Depending on regional climate variations, cropping system types, and pest species, climate change is predicted to have varying effects on agricultural pests (Sutherst *et al.* 2011). Crop resistance to pests is lowered by both heat stress and shifting precipitation patterns (Taylor *et al.* 2018). Plants' natural defences against

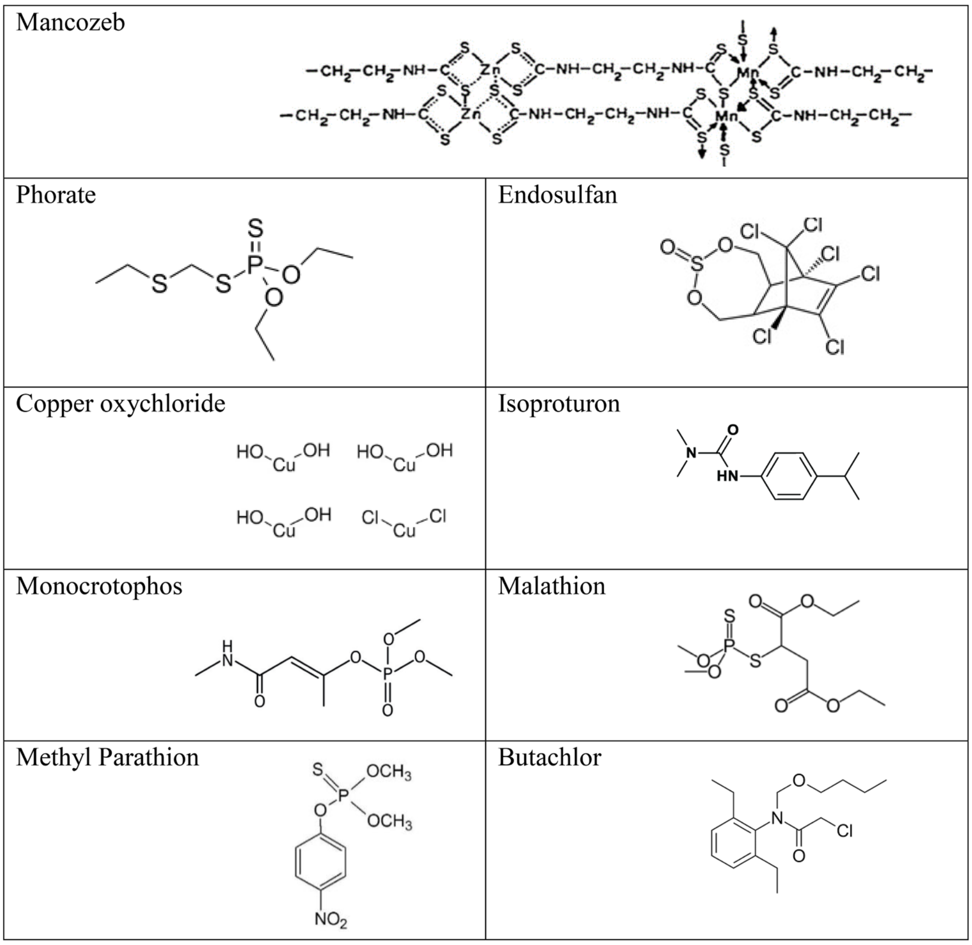


Fig. 1. Structure of some commonly used pesticides in India.

pests sometimes weakened, and drought-related modifications to plant biology may draw bugs (Skendžić *et al.* 2021).

Higher global temperatures will probably encourage an overall rise in the pace of insect development and population expansion in some locations, in addition to diminishing crop resilience. According to research, increasing CO_2 and warmth would hasten the metabolism and consumption of insect pests, which will ultimately result in decreased agricultural production (Tonnang *et al.* 2022). Increase in temperature will accelerate pesticide volatilization resulting their bioaccumulation on non-specific targets thus poisoning for anyone exposed to the toxic vapor (Lee *et al.* 2011). The breakdown products of the pesticide degradation process can either be less toxic or at times more toxic than the original product (Ji *et al.* 2020, Pathak *et al.* 2022). The greenhouse gas (GHG) emissions associated with the production, transportation and application of pesticides are linked to fossil fuel consumption during these processes and for the sustainable agricultural reduction of GHG emissions associated with pesticide use need to be minimized. Some commonly used pesticides in India are Sulfur, Endosulfan, Mancozeb, Phorate, Methyl Parathion, Monocrotophos, Isoproturon, Malathion, Copper oxychloride. Structures of some of them are given in Fig. 1.

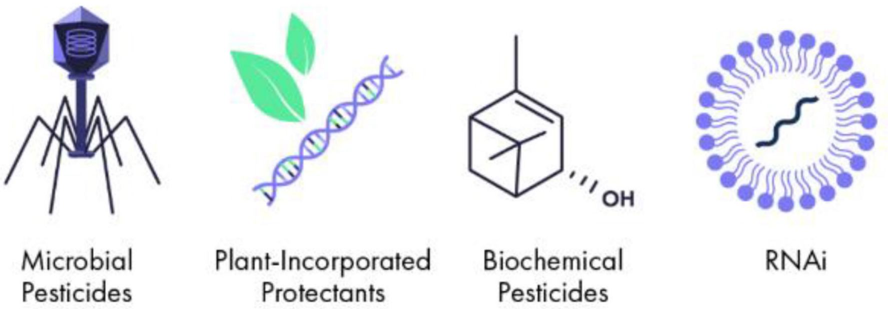


Fig. 2. Different types of biopesticides.

Biopesticides as an alternative

To feed the world's expanding population, it has been difficult to create and produce pesticides that are safe for humans, effective, and environmentally friendly. The use of biopesticides, an alternative method of pest control. Compared to their synthetic counterparts, biopesticides are safer and more effective ways to manage pests. They also have a milder environmental impact and are targeted specifically, which prevents bioaccumulation. Biopesticides are a sustainable method of controlling pests because they are derived from natural materials like micro organisms, plants and biologically derived nanoparticles. Some comparison (Dudutech 2001) between biopesticides and synthesis pesticides given in Table 1.

Generally, biopesticides have been divided into different categories according to the source of their extraction and the molecule or component that makes them up. Microbial biopesticides, biochemical pesticides, Plant-Incorporated Protectants (PIPs), GMO-based biopesticides, Nanobiopesticides are some of the categories. Some of the different types (Phorous Biotech 2024) of biopesticides is shown in Fig. 2.

Table 1. Comparison between biopesticides and synthesis pesticides.

Synthetic pesticides	Biopesticides
Harmful to non-target species	Friendly to non-target species
Serious pollution to environment	Do not cause pollution
Pests eventually become resistant	Pests never develop resistance
Non-sustainable	Sustainable
Diminishing market	Growing market

The properties of the biopesticide's source and constituent molecules affect the ways in which biopesticides defend crops against disease invasion. Structure of some commonly used botanical biopesticides and their sources are given in Fig. 3.

Some bactericides and fungicides made from microbes, for instance, may stop glucose generation in target pathogens, while others may cause a significant disruption in plasma membrane permeability or impede or disturb the process of protein translation, ultimately resulting in cell death.

Biopesticides' prospects and limitations

A thorough analysis of biopesticides and conventional synthetic pesticides reveals significant parallels, particularly in potency. Conventional pesticides have a broad-spectrum effect, work quickly, have a longer residual activity, are very effective against target pests, and are user-friendly. The detrimental consequences of synthetic pesticides have resulted in placement limits on a large number of them. Because of its selectivity and low toxicity as compared to synthetic pesticides, biopesticide use has few or no negative impacts on non-target creatures, humans, and the environment. It has been suggested that biopesticides could soon take the place of synthetic pesticides without significantly lowering agricultural yields. Some of the advantages and disadvantages

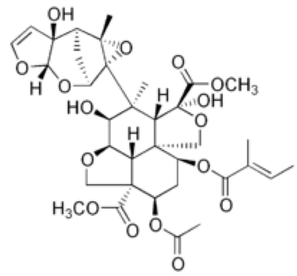
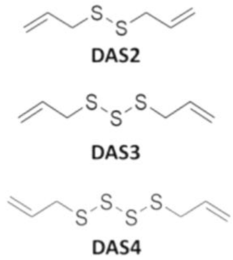
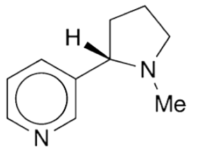
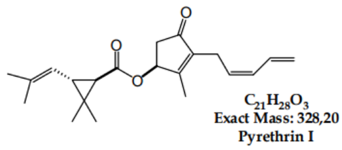
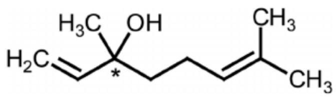
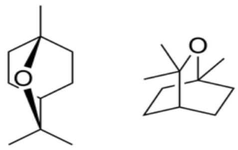
Neem  Azadirachtin	Garlic oil 
Nicotine 	flowers of the pyrethrum daisy 
Bael trees  Linalool	Eucalyptus  1,8 Cineole

Fig. 3. Structure of some commonly used botanical biopesticides and their sources.

of biopesticides are shown in Table 2.

At the moment, an operational compromise appears to be the use of biopesticides in conjunction with synthetic pesticides, which has shown effective both statistically and qualitatively. While not the perfect approach, it can reduce pollution and negative consequences associated with synthetic pesticides. Biopesticides' high specificity ensures that they only hurt the target pests while also encouraging the expansion of beneficial species like as pollinators, predators, and parasitoids, which helps protected crops as a whole. Furthermore, biopesticides have demonstrated efficacy against insect pests that have evolved tolerance to conventional pesticides. As a result, the emergence of secondary pests will be minimized, if not entirely eliminated. Biopesticides would significantly reduce the effects of harmful component bioaccumulation in the food chain, which is likely to harm humans, particularly new-borns and

Table 2. Advantages and disadvantages of biopesticides.

Advantages	Disadvantages
Biopesticides have low toxicity against humans and the environment	Due to their low toxicity, biopesticides exhibit slow action against target pest
Biopesticides are characteristically low volatile compounds does pose risks to the environment and its receptors	Poor stability is often between 2-4 days which necessitate frequent and repeated application for effective eradicationm
Biopesticides have little or no adverse effect on non-target organisms	Biopesticides limit actions against broad range of pests thereby would require diverse plant protection strategies
Cost to develop biopesticides is cost effective	Cost of production of a certified biopesticide product is comparatively higher

adults. The benefits of employing biopesticides, which range from environmental stewardship to wholesome foods and feeds for animal consumption and the reduction of health issues, have not been completely realized due to various limitations. Some constraints such as complex handling, sometimes required highly poisonous strains, complex life cycle, relatively slow activity have created a hurdles to research and development of biopesticides.

In general, biopesticides have been shown to be capable of controlling pests, but their sole usage in sustainable agriculture may be unrealistic, owing to their limited availability in many areas and their sluggish mode of action. As a result, they should be combined with existing synthetic pesticides and sprayed primarily near crop harvest times, as residual chemicals found in plants are most commonly applied at harvest times. Furthermore, this will help to preserve acceptable agriculture while biopesticides are improved.

Integrated pest management (IPM) (US EPA 2024)

The mechanism of controlling pests using a variety of methods, including habitat management, chemical and biological control measures, the use of pest-resistant cultivars and cultural practice modification, is known as an Integrated Pest Management (IPM) system. To guarantee the long-term preservation of plants, these methods might be combined. It has been reported that IPM is economical and minimizes crop production loss. A number of issues, including awareness, user preference, production industry, technology, regulation, and culture, are now limiting the implementation of IPM. The use of biological pesticides derived from plants, microbes and nano-biopesticides in integrated pest management (IPM) must thus be made more widely known. The fact that many people are aware of IPM will help to promote its acceptance, urge producers to increase production and motivate researchers to conduct additional studies on it. Over the past 20 years, there has been a growing interest in creating environmentally kindly biopesticides among academics and industry. Arthropod pests, bacterial or fungal infections, plant-parasitic nematodes, weeds and mollusks are all managed with biopesticides in an integrated pest management (IPM) program. Depending on their origin, biopesticides can be classified as botanicals, microbials, toxins, or other natural elements that can be included into various crop IPM programs. Certain products can be useful against a variety of pests and serve numerous purposes. Some active compounds have broad-spectrum activity, whereas others are species-specific.

Biopesticide regulations

Globally different agencies, regulatory bodies, committees, boards and special organizations are in function to register, monitor and control the quality of these biopesticides (Thakur *et al.* 2020). In the United States, The Food and Drug Administration (FDA), the Animal and Plant Health Inspection Service (USDAAPHIS), and the Environmental Protection Agency (EPA) are the regulatory bodies.

In India, The Central Insecticides Board and Registration Committee (CIBRC) is the the primary regulatory body for all types of biopesticide in India (Kumar *et al.* 2019). Different Central and State agricultural institutions, universities play important role for commercial manufacturing of various biopesticides (Mishra *et al.* 2020). The other regulatory bodies in India are the Central Integrated Pest Management Center (CIPMC), the National Center for IPM (NCPM), the Department of Biotechnology (DBT), the National Agricultural Research System (NARS) and the National Accreditation Board (NBA).

Biopesticides' status in India

As on November 2024, 970 biopesticides are registered (GOI 2024) in the Central Insecticides Board and Registration Committee (CIBRC). By 2050, biopesticides are expected to account for up to 50% of the pesticide market (Chakraborty *et al.* 2023) in India, where they currently make for about 9% of all pesticide consumption (Yadav 2022). A yearly growth rate of 2.5% is anticipated. But as of right now, the market for biopesticides has not grown as expected and is still quite modest when compared to the industry for synthetic pesticides. Due to several obstacles at the industrial and policy levels, the production is relatively lower. However, the National

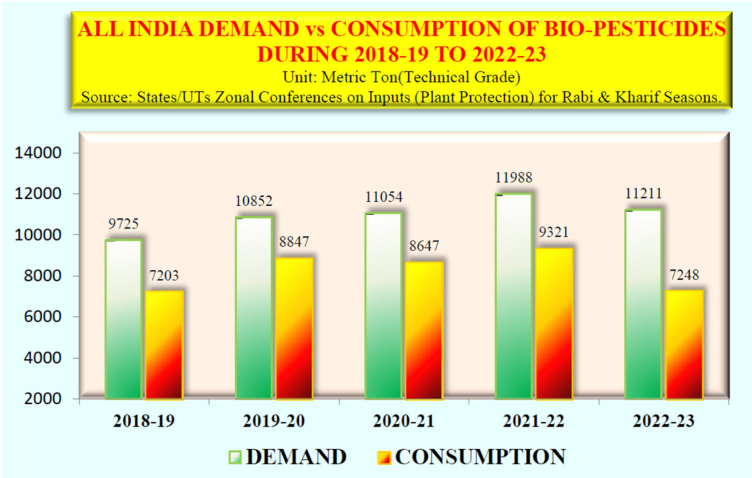


Fig. 4. Demand and consumption of biopesticides in India.

Farmer Policy (Dar *et al.* 2019) of 2007 has advocated the use of biopesticides for sustainable farming. Additionally, statistics indicate that over the past few decades, India has used more biopesticides. Demand and consumption (GOI 2024) of biopesticides in recent years in India is given in Fig. 4.

Future prospects

It will be crucial to investigate biopesticides for their full potential in agriculture, as they have shown themselves to be a good substitute for synthetic pesticides. Biopesticide availability and demand are quite low. Many parties are involved in the development and marketing of pest control products, including scientists, regulators, marketers, and final consumers. There are still a lot of issues to be resolved even though some of this chain's participants are usually involved from the start of the development process. Because these goods usually contain living things or products made from them, there are problems with the regulatory procedures, obstacles to importation, and exporting them. It has also been observed that registration costs are incredibly high. Therefore, it is evident that regulation often seen as a development barrier is necessary for the commercialization of biopesticides. The main concerns are that (i) Regulations do not differentiate between synthetic molecules and living organisms, (ii) Costly testing is required regardless of the size of the potential market, rendering niche biopesticide markets unprofitable and (iii) The registration process can be very time-consuming, even though regulations vary from country to country.

Because they need specific temperatures and conditions to survive during storage and transit, biopesticides have a limited shelf life. Therefore, further investigation into the processes that increase the stability and shelf-life of biopesticides would significantly boost their effectiveness. Because multiple biopesticides are likely to be applied to the same crop combination, it is crucial to conduct more research on their compatibility.

CONCLUSION

By 2050, there will be 9.1 billion people on the planet, having increased by 39% over the previous 20 years. Because there will be more people to feed and agriculture needs to become more productive, it will be essential to raise global food production by 60%. For crop pest control, biopesticides are therefore even more important than dangerous synthetic pesticides. It will be crucial to investigate biopesticides for their full potential in agriculture, as they have shown themselves to be a good substitute for synthetic pesticides. Biopesticide availability and demand are extremely low, which discourages both producers and consumers. Therefore, increasing the production and accessibility of biopesticides will be facilitated by providing grants or funds to researchers, entrepreneurs, producers and marketers. Given the many obstacles, using biopesticides in conjunction with currently available synthetic pesticides will be a more effective way to protect crops from pests and maintain sustainable agriculture.

Furthermore, restoring soil health, preserving diversity, ensuring animal welfare, emphasising the economical use of local and natural resources and advancing ecological justice are the goals of natural farming. One of the leading promoter for natural farming is NITI Aayog. The model's durability, long-term effects, and scientific validation all depend on multi-location studies that promote it across the nation. All of the programs that support natural farming in India need to be properly implemented for sustainable future.

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