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Pesticide used in Indian agriculture current trends and future directions

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Abstract
According to FAO 2022, pesticide use in India has exceeded 61,000 tons. Compared to major agricultural countries, pesticide use in India is significantly lower than that of Brazil, China, and Argentina. In this analysis, data regarding several India's pesticide usage trends and comprehensive consumption and demand of chemical and biopesticides data were collected, organized and summarized. Agriculture in India is a vital industry, contributing a large share to the world's food supply and supporting about 55% of the country's workforce. A growing population is putting pressure on agriculture, leading to significant changes in food production methods. It is essential to use appropriate fertilizers and pesticides to obtain high-quality and quantity of food. Pesticides are substances that kill pests. There are various pesticides such as insecticides, herbicides, fungicides, and bactericides. Unnecessary pesticide use, including over spraying and neglect of recommended dosages, is directly linked to the accumulation of harmful residues inside the surrounding environment and human health. Biopesticides are a viable alternative to chemical pesticides for sustainable agriculture and pollution reduction. India is developing several biopesticides. Plant-based and microbial biological pesticides are commercially available. The use of biological pesticides in India is 8% only. Increasing the production and use of biological pesticides is of utmost importance for sustainable agricultural development and environmental protection. The current study analyzes the utilization of both chemical and biological pesticides within the Indian agricultural sector, with a particular emphasis on the fruit and vegetable industry, and explores prevailing trends and prospective future directions.

Keywords: Pesticide use, Indian agriculture, chemical pesticides, biopesticides, sustainable agriculture

Introduction

India is an agricultural country with 70% of its population working in this sector, yet it ranks only 12th globally and third in Asia in pesticide use. Despite this, pesticide use is a major concern, as it is the highest in the world. Although India's pesticide use per hectare is low compared to countries like U.S., Japan and China, the country used 58,160 tonnes of pesticides in 2018, which is 1% of global consumption. Promoting organic pesticides, which account for only 8% of pesticide use in India, is of utmost importance for sustainable agricultural development and environmental protection (Nayak and Solanki, 2021) [12]. The types and use of pesticides around the world are increasing dramatically due to the growth of human population and crop production. It endangers both human health and environmental contamination. China is becoming the biggest producer and exporter of pesticides worldwide (Zhang *et al*., 2011) [18]. The Indian agricultural sector uses 293 registered pesticides (2021), of which a subset (130) are banned in other global regions. During 2019-2020, 61,703 metric tons of technical grade chemical pesticides were used, of which approximately 80% were classified as exhibiting extreme or high levels of toxicity (Pandey 2023) [13]. Exposure to pesticides has been linked to immune suppression, hormone disruption, intellectual disability, reproductive abnormalities, and cancer. Currently, India is the largest producer of pesticides in Asia and ranks twelfth in the world in terms of pesticide use. The majority of India's population is engaged in agriculture and is therefore exposed to pesticides used in agriculture. Although the average pesticide use in India is much lower than many other developed economies, the problem of pesticide residues in India is very high (Abhilash and Singh, 2009) [1]. Exposure to commercial and environmental pesticides poses major risks to human health. The indiscriminate and repeated use of these chemicals leads to biodiversity loss, insect resistance, and widespread ecological imbalances. Many pesticides are persistent, accumulating in soil, leaching into groundwater and surface water, and contaminating the wider environment. In India, pesticides remain essential for controlling ticks, lice, and other ectoparasites in livestock. However, the lack of effective alternative control methods necessitates increased reliance on chemicals, driving the development of pest resistance. Furthermore, due to the persistent nature of pesticides, they accumulate in animal tissues, which leads to human exposure through consumption of contaminated meat, milk, eggs, and seafood (Kumar *et al*., 2013) [10]. Global pesticide consumption is estimated at 20 million metric tons per year, with China being the major source, followed by the United States and Argentina, where consumption is growing rapidly. It is projected to increase to 3.5 million metric tons by 2020. Although pesticides provide agricultural benefits, their widespread use poses significant environmental and health risks due to their bioaccumulative and persistent characteristics (Sharma *et al*., 2019) [15]. The application of pesticides in Indian agriculture has risen sharply since 1957-58. In the years before and the first decade of the Green Revolution, the growth in pesticide use exceeded the growth in agricultural production. However, in the post-Green Revolution period (after 1974-75), the increase in production has been found to be much higher than the increase in pesticide use, which is attributed to the development of pest and disease resistant varieties (Chand and Birthal, 1997) [5]. Pesticide use and share of crop production cost, the pesticide use remained high during the early stages of the Green Revolution and peaked in 1988-89. Pesticide use in India was high from 1955-56 to 2003-2004. Between 1999-2000 and 2000-2001, pesticide use decreased significantly from 75,418 to 43,584 tonnes. Between 2001-02 and 2003-04, pesticide use increased slightly due to various reasons (Shetty *et al*., 2010) [16].

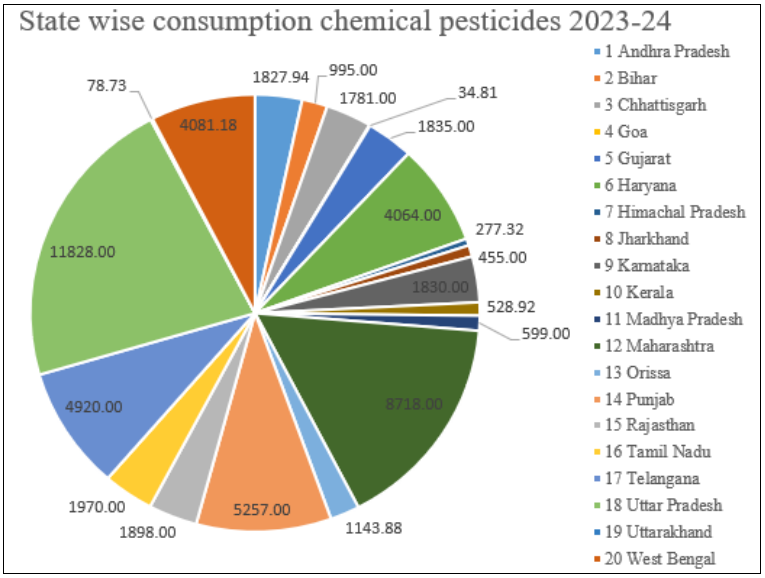

Fig 1: State-wise chemical pesticide consumption in 2023-24 in India (Data source: GOI 2024) [7]

According to the fig.1 during 2023-2024, The states with the largest consumption, in descending order, are as follows, State-by-state chemical pesticide use in 2023–2024: Uttar Pradesh (11828.00), Maharashtra (8718.00), Telangana (4920.00), West Bengal (4081.18), Haryana (4064.00), Punjab (5257.00), Tamil Nadu (1970.00), Rajasthan (1898.00), Andhra Pradesh (1827.94), Gujarat (1835.00), Karnataka (1830.00), Chhattisgarh (1781.00), Orissa (1143.88), Bihar (995.00), Madhya Pradesh (599.00), Kerala (528.92), Jharkhand (455.00), Himachal Pradesh (277.32), Goa (34.81), and Uttarakhand (78.73).

There is a wide range of pesticide use among the states of India in 1991-2012 in the period of two decades. India's pesticide economy is in nature on more exports. The rate of domestic use of pesticides, however, pesticide use in Indian states has shown fluctuations across decades, although the overall trend is negative (-2.48%). Between 2000 and 2013, 17 states and Union Territories recorded a positive increase. The states of Jammu and Kashmir, Andaman and Nicobar Islands and Tripura had the highest growth rates. Importantly, Maharashtra, Uttar Pradesh, Andhra Pradesh, Haryana and Punjab account for approximately 70 % of the total pesticide use in India (Devi *et al*., 2017) [6]. Global pesticide sales were stable in the 1990s, with herbicides accounting for 47%. From 2007 to 2008, fungicides/bactericides grew rapidly, while herbicides continued to dominate. Europe is the top consumer, followed by Asia. U.S., France, China, Brazil and Japan are the major producers, consumers and traders. Vegetables and fruits account for largest share of pesticide use, and herbicides are used primarily on corn crops (Zhang *et al*., 2011) [18].

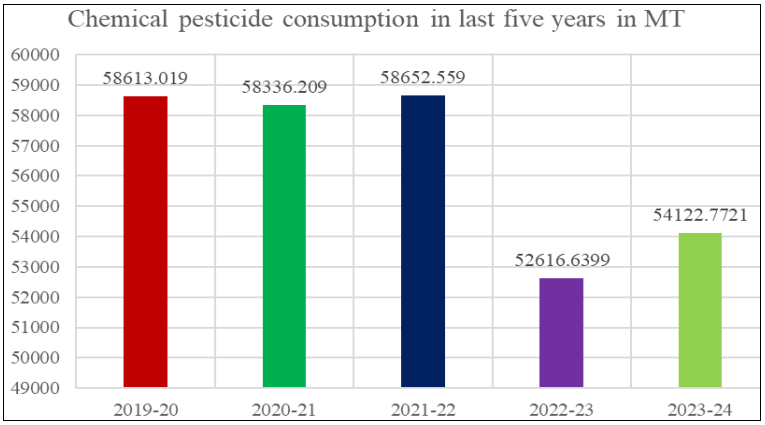

Fig 2: Use of chemical pesticides in India in the last five years (Data source: GOI 2024) [7].

In figure. 2 have shown chemical pesticide consumption fluctuations over the past five years. In 2019-20, the use was 58,613.02 MT, which slightly decreased to 58,336.21 MT in 2020-21. It increased slightly in 2021-22 and reached 58,652.56 MT. However, in 2022-23, the use declined significantly to 52,616.64 MT. Then, the use improved in 2023-24 and reached 54,122.77 MT. Overall, despite the fluctuations, the consumption of chemical pesticides in 2023-24 is still lower than the use five years ago.

In India, chemical pesticides have emerged as an important tool for managing pests and diseases, mainly in the agricultural and public health sectors. Compared to other rich nations, India uses relatively low amounts of pesticides - just 0.5 kg/ha. Yet, the country's food contains high levels of pesticide residues. In the last ten years, the demand for pesticides has increased, with Andhra Pradesh recording the highest increase, followed by Maharashtra. On the other hand, Karnataka saw a decline in pesticide use from 2005-06 to 2012-13 (Chahal *et al*., 2016) [3].

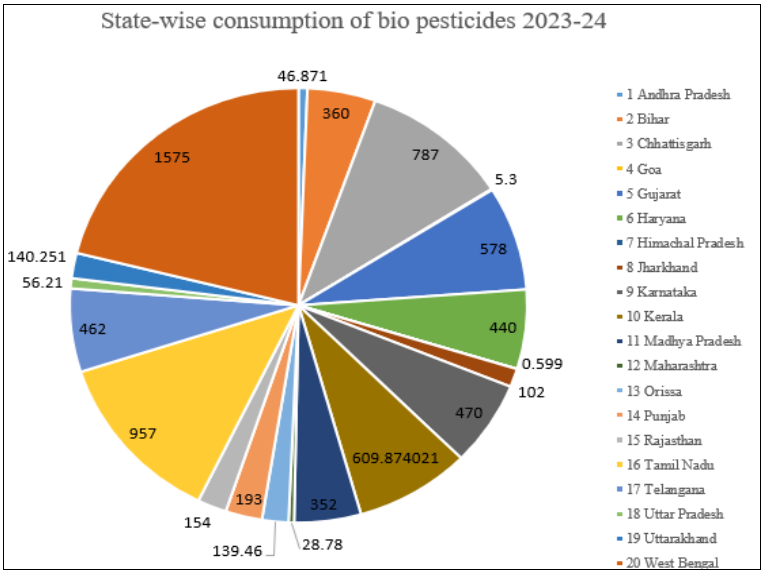

Fig 3: State wise biopesticides consumption in 2023-24 in India (Data source: GOI 2024) [7]

According to the fig.3 during 2023-2024, The highest use of biopesticides in India is in Uttar Pradesh, where 140,251 units are used, followed by Bihar (46,871 units) and Andhra Pradesh (46,871 units). The states of Madhya Pradesh (599 units), Maharashtra (440 units) and Karnataka (462 units) are also included. However, it is important to note that the use of organic pesticides in most states is relatively low compared to Uttar Pradesh.

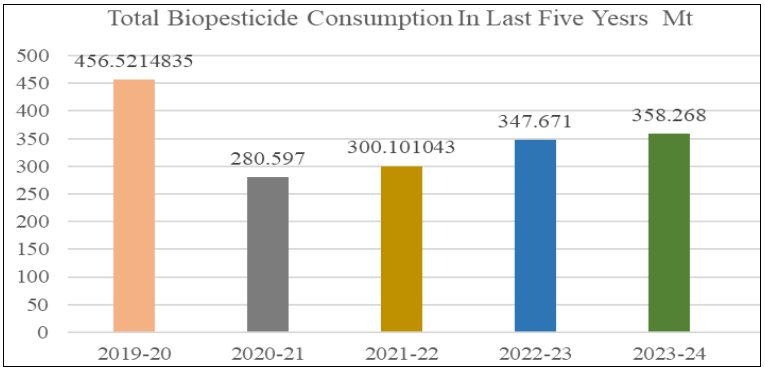

Fig 4: Biopesticides consumption from 2019 to 2024 in India (Data source: GOI 2024) [7]

The fig.4 shows the consumption of biopesticides fluctuated / various trends in the last five years. In 2019-20, the use was highest at 456.52 MT. It then declined significantly to 280.60 MT in 2020-21. There was a slight increase to 300.10 MT in 2021-22. In 2022-23, the use increased significantly to 347.67 MT and in 2023-24, it increased to 358.27 MT. Despite the fluctuations, the use in the last two years shows a positive growth trend.

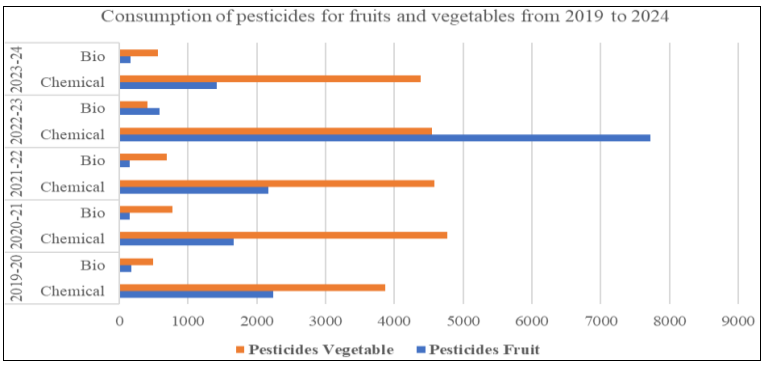

Fig 5: Consumption of chemical pesticides and biopesticides in MT for fruits and vegetables from 2019-24 in India (Data source: GOI 2024) [7]

The fig.5 shows a rise in applications of chemical pesticides on fruit and vegetables between 2019 and 2024, with the use of vegetables typically outpacing that of fruits. Use of vegetable pesticides has been significantly increased in 2023. Additionally, data demonstrates that, in contrast to biopesticides, the majority of chemical pesticides are applied on fruits and vegetables.

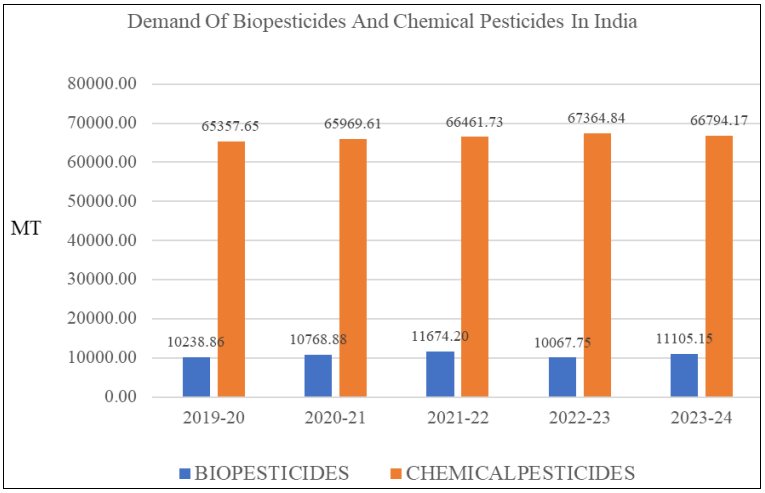

Fig 6: Shows the demand of biopesticides and chemical pesticides from 2019-2024 in India (Data source: GOI 2024) [7]

Figure 6 shows that the demand for chemical pesticide use in India has been increasing steadily over the last five years, from 65,357.65 MT in 2019-20 to 66,794.17 MT in 2023-24. In contrast, the demand for biopesticides has remained significantly low, albeit showing some fluctuations. Starting from 10,238.86 MT in 2019-20, the demand for organic pesticides increased to 11,674.20 MT in 2021-22 and then declined to 10,067.75 MT in 2022-23 and then improved slightly to 11,105.15 MT in 2023-24. Despite the growing interest in biopesticides and sustainable farming, the data shows that chemical pesticides continue to dominate the Indian market.

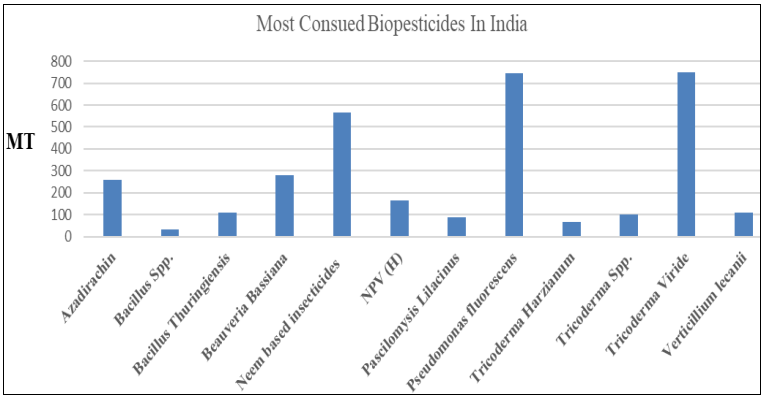

Fig 7: Most consumed biopesticides in 2023-2024 in India (Data source: GOI 2024) [7]

The fig.7 shows the most used biopesticides in 2023-24 in India, *Trichoderma viride* and *Pseudomonas florescence*are the most extensively used biopesticides in India, with a total used of over 700 metric tonnes. The consumption of neem-based pesticides is also relatively high over 500 metric tonnes. Azadirachtin is used moderately around 200 metric tonnes. The consumption levels of the remaining biological pesticides listed are significantly lower less than 200 metric tonnes.

Although there has been significant progress in the market for biological pesticides, their share in pest management solutions is relatively small. Globally, the production of biological pesticides exceeds 3,000 tonnes per year and this figure is growing rapidly. However, in India, biological pesticides account for only 4.2% of the total pesticide market. The Government of India has promoted their use through various agricultural programmes. Despite this, biological pesticides face numerous challenges at the domestic level. However, they are expected to expand at an astonishing rate of 10% per year. The Ministry of Agriculture of India regulates the use of pesticides under the Pesticides Act, 1968. The major biological pesticides produced and used in India include Trichoderma, Bacillus thuringiensis, Nuclear Polyhedrosis Virus and Neem based pesticides (Chakravarti *et al*., 2023).

Current Trends and Future Directions

From 1957 to 1958, pesticides application in Indian agriculture rises rapidly. In the pre-green revolution period and the first ten years of the Green Revolution, pesticide use increased faster than production. However, in the post-Green Revolution period (1974 to 1975), production increased significantly more than pesticide use; this is attributed to the development of pest and disease resistant varieties. Green Revolution technology cannot be held responsible for the indiscriminate use and increase in use of pesticides, as there is evidence that pesticide use would have increased much faster in the absence of technology (Chand and Birthal, 1997) [5]. India prioritizes agricultural development, relying on pesticides to increase food production and control diseases. However, more exposure to pesticides poses major health risks like hormonal disruption, immune suppression and cancer. Despite its lower average pesticide use compared to developed nations, India faces high pesticide residue problems, which affect agricultural exports. Being Asia's leading pesticide producer and the

world's twelfth largest user, India needs to focus on pesticide safety, regulation, proper use technologies and integrated pest management to reduce human and environmental harm. Highlights the lack of research in these areas and pesticide use technologies to develop policies for rational use and reduce related problems (Abhilash and Singh, 2009) [1]. In India insecticides and fungicides contribute the largest portion of pesticide production with herbicides and rodenticides coming in second and third place. However, the use of pesticides has declined from over 70% in 2003 and 2004 to 39% in 2016 and 2017. Over time, the use of fungicides, herbicides and rodenticides has been increasing. There has been a significant increase in the use of fungicides, mainly in the cultivation of fruit and vegetable crops. The major pesticides produced in India include Profenophos, Acephate, 2-4-D and Mancozeb (Subash *et al*., 2017) [17]. Pesticides are essential to reduce damage from weeds, diseases and insects. However, growing concerns about their harmful effects on human and environmental health necessitate a rigorous analysis of their use patterns. India uses 0.4 kg of pesticides per hectare, which is less than China's 1.83 kg. However, the problem of pesticide residue contamination in the food chain requires urgent attention (Reddy *et al*., 2024) [14]. In India, pests cause crop losses worth over Rs 60 billion annually. Weeds account for the largest share of this loss at 33%, followed by diseases at 26%, insects at 20%, birds and rodents at 10% and other factors at 11%. This problem is expected to worsen as new pests and diseases emerge, necessitating increased pesticide use in the future. India's annual pesticide market is estimated to be worth Rs 50 billion and is expected to experience rapid expansion, making the country a major player in the global pesticide industry. In India, pesticide use increased 30-fold in fifty years (from just 2,35,000 tonnes between 1959 and 2000 to about 60,000 tonnes) (Bunch *et al*., 2003) [2]. The use of pesticides in India began in 1948 with imported DDT for malaria control and BHC for locust control. Domestic production of these pesticides commenced in 1952, and by 1958, output surpassed 5,000 metric tons. Currently, approximately 145 pesticides are registered in India, with production reaching 85,000 metric tons. Despite relatively low overall pesticide application, indiscriminate use has resulted in widespread food contamination. Notably, 51% of Indian food products contain pesticide residues and 20% exceed global maximum residue limits. To mitigate human exposure, future strategies emphasize pesticide safety, stricter regulations, biotechnology, biopesticides, and natural alternatives like neem extract (Gupta, 2004) [8]. Because of their eco-friendliness and target precision, biological insecticides are becoming more and more popular worldwide. However, in developing nations like India, the use of biological pesticides is still relatively low when compared to conventional chemical pesticides. Biological pesticides encounter several obstacles at the local level, despite the Indian government's efforts to encourage their use by incorporating them into various agricultural initiatives. Farmers' waning interest in biological insecticides and their decreased adaptability are causes for concern. But technological problems with production, production, and use in agro-ecological systems have also raised doubts about their long-term viability (Mishra *et al*., 2020) [11]. Citing health, environmental, and pollinator issues, consumers are growing more worried about the use of pesticides on food and houseplants. The green industry is looking into alternatives like biological control, which improves sustainability and reputation while lowering the need for pesticides, their resistance, and safety issues. Biological control is an approach to pest management that is grounded in understanding. Successful implementation of a biological control program requires extensive study of the pests, their natural enemies, their environment, other pest management techniques, and the relationships between these factors. Success requires a lot of planning, adjustments to current production and pest management processes, and trial-and-error (Jeffers and Chong 2021) [9].

Conclusion

More than last 6 decades, pesticides use and their demand tremendously increase over the world as well as in India. Pesticide help to control pests in agriculture and all other areas. Pesticides have provided significant benefits to global agriculture, leading to higher yields and improved farmer incomes.

In 2023-2024, Uttar Pradesh, lead chemical pesticide use with 11828.00 MT, followed by Maharashtra (8718.00 MT) and Telangana (4920.00 MT), respectively. In 2023-2024, The highest use of biopesticides in India is in Uttar Pradesh, where 140,251 MT are used, followed by Bihar (46,871 MT) and Andhra Pradesh (46,871 MT). The highest Bio pesticide uses of 456.52 metric tons (MT) was recorded in 2019-20, followed by a significant decrease from 2020 to 2024. Chemical pesticides are used more than biological pesticides on fruits and vegetables. While the spread of biopesticides and sustainable agriculture is increasing, chemical pesticides still dominate the Indian agricultural market.

Trichoderma viride and *Pseudomonas florescence*, a widely used biopesticides in India, helps protect crops from many diseases. Biopesticides are a viable alternative to chemical pesticides for sustainable agriculture and pollution reduction. India is developing several biopesticides. There are environmentally friendly microbial and plant-based biological insecticides on the market. The use of organic pesticides in India is 8% only. Increasing the production and use of organic pesticides is of utmost importance for sustainable agricultural development and environmental protection.

The use of biopesticides in India is only 8%. Promoting the production and use of biological pesticides is of utmost importance for sustainable agricultural development and environmental protection.

As a sustainable alternative to chemical pesticides, biopesticides effectively reduce environmental damage and enhance ecological balance. Their selective targeting of pests reduces collateral damage to beneficial organisms, thereby maintaining biodiversity and supporting natural ecosystem functions. Furthermore, the rapid degradation of biopesticides reduces the risk of persistent residues, thereby protecting both human and environmental health. Biopesticide policies enable farmers to grow healthy crops, protect the environment, and contribute to a more resilient and sustainable agricultural system.

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