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RESEARCH ARTICLE

Biopesticide Market and Regulatory Landscape with Determinants of Farm-Level Use in India

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Abstract

The reliance on synthetic pesticides for pest management in crop production has led to adverse environmental impacts such as pollution, non-target organism harm, and the development of pesticide-resistant crop pests. In response, biopesticides have emerged as a sustainable alternative, including microbial pesticides, biochemicals from micro-organisms and natural sources, and genetic processes for pest protection in agriculture. Despite their benefits, the adoption of biopesticides remains low in India. This paper provides a summary of global and national biopesticide markets, tracks trends in biopesticide demand and consumption in India at national and state levels, identifies determinants of expenditure on biopesticides, and reviews regulatory systems in selected countries. The findings indicate slow growth in biopesticide consumption in India, emphasizing the need for government intervention to promote this sector. Our analysis suggests that farmer organizations can play a crucial role in promoting farmers' expenditure on biopesticides. India can learn from regulatory systems in other countries to streamline the registration process and ensure adherence to safety and efficacy standards. Biopesticides offer an environmentally friendly and sustainable alternative to chemical pesticides, reducing pollution and supporting ecological balance in agriculture. Therefore, promoting their formulation and utilization is essential for advancing sustainable agricultural development and mitigating the environmental impact of chemical pesticides.

I. Introduction

The agricultural and allied sectors play a vital role in India's economy by contributing significantly to the nation's Gross Domestic Product and providing employment to approximately 58% of the population[1]. The introduction of chemical pesticides, fertilizers, and high-yielding varieties during the Green Revolution helped address food scarcity in the country and boosted productivity. Pesticides are particularly important in the Green Revolution, as pest-related yield losses in India range from 10-30%[2][3]. In 2022, India's pesticide consumption was 53,000 tons, with per-hectare pesticide use at 0.37 kg/ha, which is considerably lower than countries like China (13 kg/ha), Israel (13 kg/ha), South Korea (12 kg/ha), Japan (12 kg/ha), Brazil (6 kg/ha), and the USA (3 kg/ha)[4]. India's total and per capita pesticide usage remains significantly lower compared to several competing countries, mainly developed nations, yet there are emerging sustainability concerns. Prolonged and indiscriminate usage of pesticides leads to insecticide resistance, biomagnification of insecticides, soil and water contamination, and a significant increase in harmful residues in agricultural products. Hence, policymakers are striving to shift the technologies and practices followed conventionally towards sustainable alternatives, and biopesticides are promising among such alternatives.

The term "biopesticide" encompasses microbial pesticides, biochemicals derived from microorganisms and other natural sources, as well as processes involving the genetic incorporation of DNA into agricultural commodities to provide protection against pest damage (referred to as plant-incorporated protectants). Biopesticides are derived from plants, animals, and microorganisms and are employed specifically for managing harmful organisms. While biopesticides pose minimal risk to the environment and human health, they are generally biodegradable, target-specific, and capable of addressing issues related to pest resistance caused by chemical pesticides. The integration of biopesticides into sustainable agriculture enhances social acceptability, economic productivity, and environmental protection, aligning with the tripartite concept of sustainable development. By incorporating the principles of green chemistry and the tripartite concept, biopesticides offer a comprehensive approach to sustainable agricultural management[5]. Hence, biopesticides can play a pivotal role in safeguarding plants as well as enhancing crop quality and productivity in the future[6][7][8].

The adoption of biopesticides among farmers in India remains limited despite the potential benefits. To address this, the government has implemented multiple initiatives and programs aimed at promoting the use of biopesticides. These include the Sikkim Organic Mission (SOM), National Programme for Organic Production (NPOP), Organic Farming Policy (OFP), Strengthening and Modernizing Pest Management Approach in India (SMPMA), Capital Investment Subsidy Programme (CISP), National Action Plan on Climate Change (NAPCC), National Mission for Sustainable Agriculture (NMSA), "Paramparagat Krishi Vikas Yojana" (PKVY), Soil Health Management (SHM), and Zero Budget Natural Farming (ZBNF). These initiatives are designed to facilitate the adoption of microbial biopesticides in India. Presently, there are 361 bio-production units, with 141 operating in the private sector without government grant aid and 38 receiving government grant aid.

This study focuses on examining the market, categories, and regulation of biopesticides, as well as their production, consumption, and usage patterns in India. The analysis also encompasses technological advancements that enhance biopesticide efficacy, along with the role of biopesticides in agriculture and sustainable development. We also address the limitations and future prospects in this area, along with identifying the factors influencing the adoption of biofertilizers among paddy farmers.

II. Data and Methodology

The study used secondary data from various sources. Data on the production, consumption, and usage of biopesticides in India from 2018-19 to 2022-23, covering a five-year time series, was collected from the Directorate of Plant Protection, Quality, and Storage, Ministry of Agriculture and Farmers Welfare, Government of India. Additionally, the study utilized the survey dataset from the "Situation Assessment of Agricultural Households and Land and Livestock Holdings of Households in Rural India" of the 77th National Sample Survey (NSSO) round. This comprehensive country-wide dataset covers information from 5940 villages and 45,714 agricultural households. The reference period for data collection was the agricultural year from July 2018 to June 2019. Since the study specifically targeted the analysis of biopesticide use in paddy during the Kharif (monsoon) season, the dataset comprises information from 14313 farmers. The data on biopesticide market and consumption trends were analyzed using graphs and tables. We used the Seemingly Unrelated Regression (SUR) model to study factors influencing farmers' spending on chemical pesticides and biopesticides. This model accounts for potential correlations between the error terms of the equations, providing more efficient estimations. The parameters of the SUR model are estimated using Generalized Least Squares, improving the efficiency of parameter estimates. The model is specified as follows:

$$Y_{i1} = X'_{ij1}\beta 1 + \varepsilon_{i1}$$

$$Y_{i2} = X'_{ij2}\beta 2 + \varepsilon_{i2}$$

Where

i = farmer id,

Y_{i1} = expenditure on chemical pesticides,

Y_{i2} = expenditure on biopesticides

X'_{i} = Vector of determinants of adoption,

β_j = Vector of unknown parameters to be estimated (j=1,2), and

ε = Error term

III. Results and Discussion

An Overview of the Global Biopesticides Market

The biopesticides market encompasses various regions, including North America, Europe, Asia-Pacific, Latin America, and the Middle East and Africa. Each region presents unique opportunities and challenges based on local agricultural practices, regulatory environments, and market maturity. The biopesticides market is segmented in several ways: (i) by formulation, with liquid formulations expected to experience the fastest growth due to advantages such as extended shelf life, high purity, and ease of handling; (ii) by product, with bioinsecticides leading the segment driven by increasing awareness of the adverse effects of chemicals and supportive government regulations; (iii) by mode of application, encompassing foliar spray, seed treatment, soil treatment, and post-harvest applications; (iv) by application, covering crops (grains and cereals, oil seeds, fruits and vegetables) and non-crop applications (turf and ornamental grass, other non-crop types); and (v) by ingredient, including microbial (bacteria, viruses, fungi, nematodes, and other microbials) and biorational ingredients like botanicals, insect growth regulators, feeding deterrents, repellents, and others.

The global biopesticides market is currently witnessing substantial growth driven by various factors contributing to its expansion and development. Recent market research reports indicate that the market is expected to reach USD 13.9 billion by 2028, with a Compound Annual Growth Rate (CAGR) of 15.9% from 2023 to 2028. Another analysis estimates the market to expand from USD 6.62 billion in 2023 to USD 13.38 billion by 2028, with a CAGR of 15.10%[9]. Similarly, Triton Market Research predicts the market to grow from $5.8 billion in 2022 to $17.9 billion by 2030, at a CAGR of 15.13%. Several key drivers are propelling the growth of the biopesticides market, including the increasing demand for organic food, growing awareness of the harmful effects of synthetic pesticides, and the expansion of the organic food sector. Nonetheless, the biopesticides market also encounters several challenges, such as technological limitations and the preference for chemical pesticides, particularly in developing countries. Despite these challenges, there exist numerous opportunities in developing regions such as Asia Pacific and South America, driven by population growth, rising disposable incomes, and technological advancements.

The biopesticides market is distinguished by the presence of major companies such as BASF SE, Bayer AG, Syngenta, UPL Limited, FMC Corporation, Marrone Bio Innovations, Novozymes, Nufarm, Isagro S.p.A, Certis USA L.L.C., Koppert, Biobest Group NV, SOM Phytopharma, Valent BioSciences, and STK Bio-Ag Technologies. These companies are actively engaged in strategic initiatives such as product launches, collaborations, and acquisitions aimed at reinforcing their market positions. Notable recent strategic maneuvers include the Andermatt Group AG launching Plutex for managing the diamondback moth in cruciferous crops and Bayer AG partnering with Microsoft for Ag Powered Services, a cloud-based solution for the agri-food industry. These initiatives underline the industry's emphasis on innovation and strategic partnerships. The escalating demand for safer field applications of products like biopesticides presents compelling investment opportunities. Investors are increasingly drawn to this market due to its potential for sustainable growth and favorable environmental impact.

Consumption of Biopesticides in India - National Level

Figure 1 illustrates the demand and consumption trends of biopesticides in India over the past 5 years, demonstrating a gradual increase in both parameters. In 2018-19, the demand for biopesticides were 9725 metric tonnes, of which 7203 metric tonnes were consumed. By 2022-23, the demand for biopesticides had only increased to 11211 metric tonnes, while consumption remained relatively stable at approximately 7248 metric tonnes. One potential factor contributing to this sluggish increase could be a lack of awareness among farmers regarding the benefits and availability of biopesticides. However, fluctuations in consumption and demand may also be attributed to the impact of the COVID-19 pandemic, which resulted in disruptions in the supply chain and other challenges affecting pesticide availability. Biopesticide consumption peaked at 9321 metric tonnes in 2020-21 before declining to 7248 metric tonnes in the subsequent year. This decline in biopesticide usage can be attributed to the implementation of the Stockholm Convention, which emphasized higher application standards, and the development of integrated pesticide management programs[10][11].

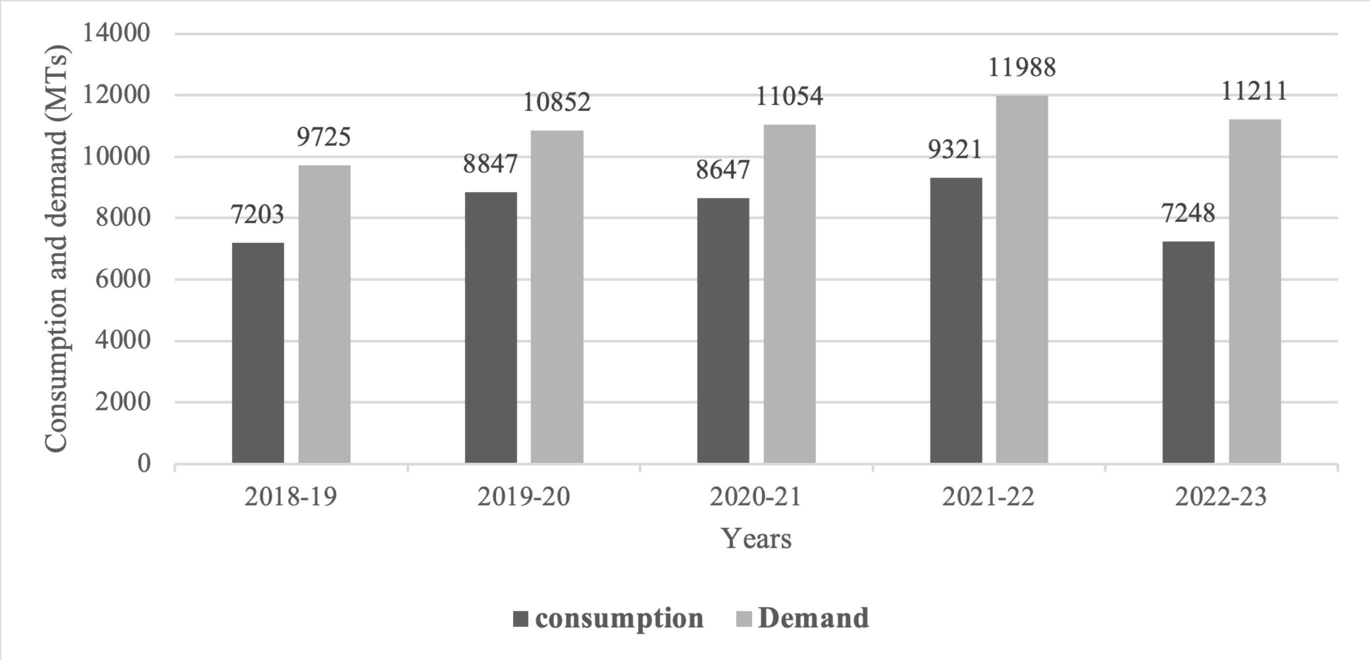

Figure 1. Demand and Consumption of Biopesticides in India

Consumption of Biopesticides in India- State Level

During the year 2022-23, the state of West Bengal reported the highest total biopesticide consumption, approximately 1234 metric tonnes, followed by Tamil Nadu (907 MT), Chhattisgarh (740 MT), and Kerala (628 MT). As depicted in Figure 2, the combined bio-pesticide consumption of West Bengal, Tamil Nadu, and Chhattisgarh constituted 41% of India's total bio-pesticide consumption. Notably, the top five states account for 50% of biopesticides consumed nationally. Moreover, as demonstrated in Figure 3, Kerala stands out with the highest consumption at 3.1 units, followed by West Bengal at 2.3 units. Uttarakhand and Tamil Nadu both register a consumption of 1.9 units, while Chhattisgarh closely follows with 1.6 units. Haryana and Assam report 1.2 and 1.0 units, respectively. Moderately consuming states include Bihar and Jharkhand, each at 0.7 units, and Gujarat at 0.6 units. The all-India average of 0.5 units matches Andhra Pradesh's consumption. Punjab and Karnataka consume 0.4 units and 0.2 units respectively. Conversely, the lowest consumption levels are observed in Odisha (0.2 units), Rajasthan (0.1 units), Uttar Pradesh, Jammu & Kashmir, Maharashtra, and Himachal Pradesh, each reporting negligible or zero consumption. This distribution points to significant regional variations in biopesticide use, with certain states exhibiting notably higher adoption rates compared to others.

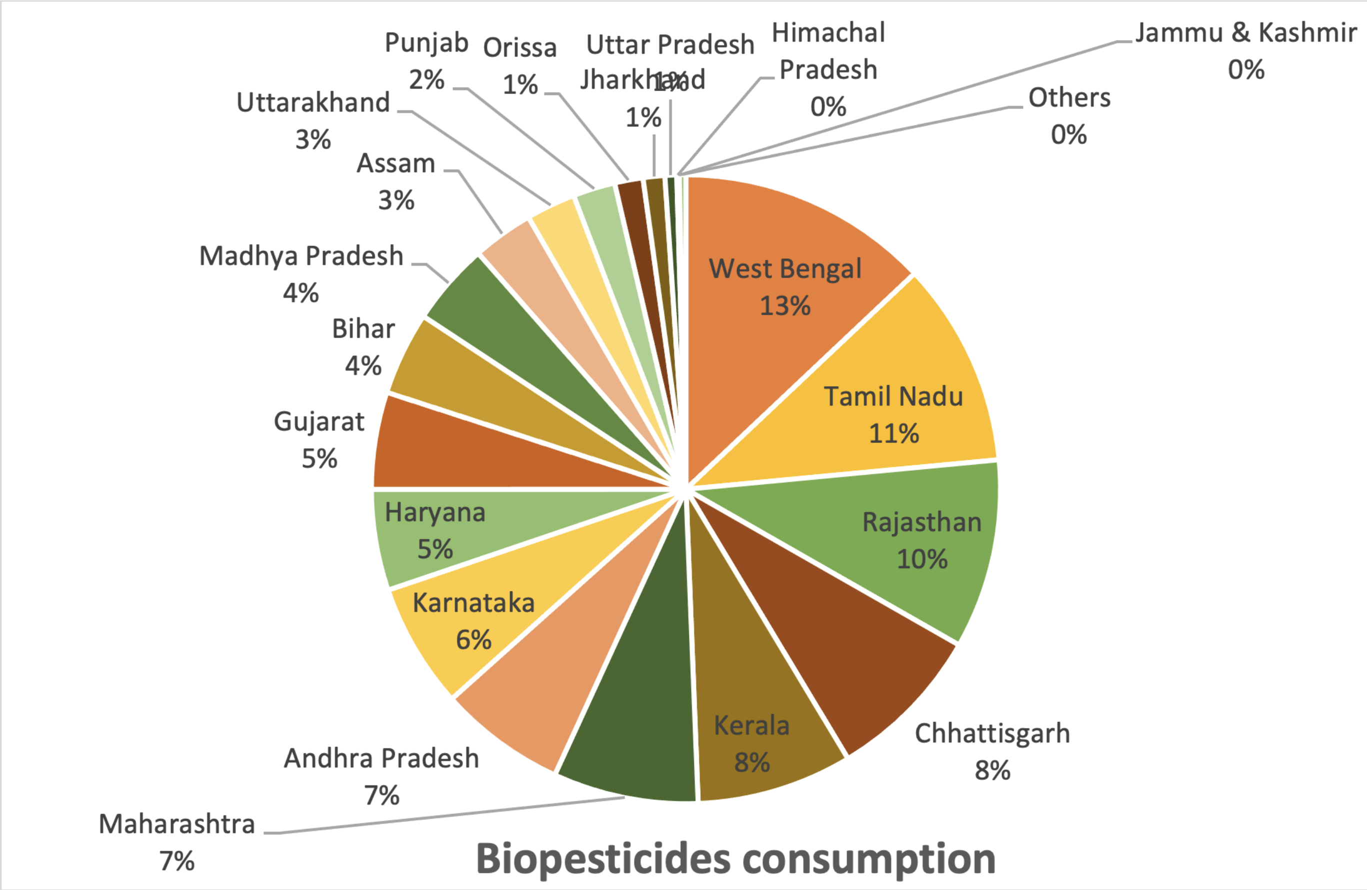

Figure 2. State Wise Total Consumption of Biopesticides in India

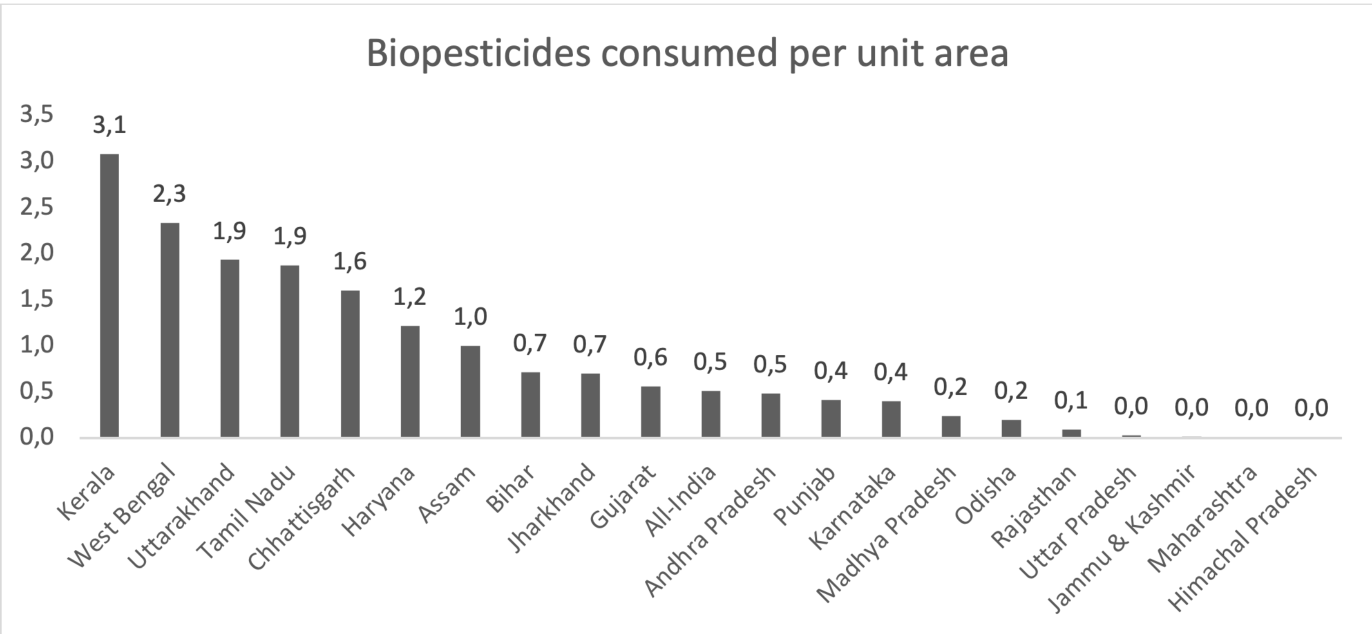

Figure 3. State Wise Consumption of Biopesticides Per Unit Area

A Snapshot of the Indian Biopesticides Market

In India, biopesticide consumption constitutes approximately 9% of the total pesticide usage, which remains comparatively low. Nevertheless, there has been a substantial rise in biopesticide utilization in India over recent decades. For instance, the consumption of neem, one of India's most extensively utilized biopesticides, surged from 83 metric tonnes (MT) in 1994–1995 to 686 MT in 1999–2000. Similarly, the consumption of *Bacillus thuringiensis* (Bt) increased from 40 to 71 MT during the same period. As per PPQS data, the overall consumption of biopesticides in India escalated by 40% from 2014–2015 to 2018–2019 (GOI, 2020). Currently, there are 970 biopesticide products registered with the Central Insecticides Board and Registration Committee (CIBRC), which oversees the regulation of biopesticides in India[12][13][14]. Biopesticide production comprises bacterial (29%), fungal (66%), viral (4%), and other types (1%, including plant-based and pheromone-based biopesticides)[13]. In comparison to other products such as bioherbicides, biofungicides, and bionematicides, bioinsecticides are in high demand and command around 70% of the market, with a specific emphasis on delivering enhanced control and food safety (Market, 2021). In India, only 12 different kinds of biopesticides under the Insecticide Act of 1968 have been registered[15].

The primary biopesticides manufactured and utilized in India are Neem-based insecticides, *Bacillus thuringiensis*, NPV, and *Trichoderma*. The list of registered chemical pesticides is more extensive, totaling more than 230 synthetic compounds (Sharma et al., 2018). *Trichoderma*, *Pseudomonas*, and NPV-H (nuclear polyhedrosis virus of *Helicoverpa armigera*) are the most commonly employed insecticides in 2019-20. The majority of biopesticides, barring some used in agriculture, find application in public health. Furthermore, transgenic plants and beneficial organisms, referred to as bio-agents, are also utilized for pest management in India[16]. A significant technological advancement in the field of biocontrol transpired in India when chemical pesticides failed to curb pests such as *Helicoverpa armigera* and *Spodoptera litura* in cotton crops[17]. Biocontrol emerged as the sole technology capable of addressing chemical pesticide resistance in pest insects in a safe, cost-effective, and environmentally beneficial manner. Subsequently, biopesticides were integrated into integrated pest management (IPM), which had previously relied solely on the application of chemical pesticides[8][13].

Determinants of Expenditure on Chemical and Biopesticides Among Paddy Farmers

In our dataset, only 11.39 percent of the farmers adopted biopesticides. As the farmer's decision to spend on biopesticides is dependent also on their expenditure on chemical pesticides, the seemingly unrelated regression (SUR) model was utilized to identify the determinants of expenditure on chemical pesticides and biopesticides. The coefficient estimates indicate that several variables significantly affect biopesticide expenditure. Household size demonstrates a significant positive relationship, with a coefficient of 13.107, suggesting that larger households are likely to spend more on biopesticides. Agricultural training also shows a positive impact, though it is not statistically significant at conventional levels. Education, surprisingly, does not have a significant effect on biopesticide expenditure, as evidenced by its small negative coefficient of -1.083. Gender appears to have a positive, albeit statistically insignificant, effect on biopesticide expenditure. Notably, membership in farmer organizations is positively associated with biopesticide expenditure, indicating that farmers involved in such organizations are more inclined to invest in biopesticides. The holding of a Soil Health Card is another important determinant, suggesting farmers with access to soil health information spend more on biopesticides.

Crop insurance and expenditures on seeds and irrigation are also positively and significantly correlated with biopesticide spending. For comparison, chemical pesticide expenditure shows significant positive relationships with several variables, including age, agricultural training, household size, and membership in farmer organizations. However, crop insurance negatively affects chemical pesticide expenditure, contrasting with its positive impact on biopesticides. The Breusch-Pagan test of independence confirms the appropriateness of using the SUR model, with a chi-squared value of 9.091 and a p-value of 0.002, indicating a significant relationship between the error terms of the two regression equations. This suggests that accounting for the correlation between the errors improves the efficiency of the estimates.

Table 1. Estimates of Determinants of Expenditure on Chemical Pesticides and Biopesticides Using Seemingly Unrelated Regression

Variables	Chemical pesticides		Biopesticides	
	Coefficient	Standard error	Coefficient	Standard error
Age (years)	5.652***	1.599	0.687	0.636
Gender (male=1)	-69.836	70.678	14.751	28.123
Education (years)	-18.046**	8.098	-1.083	3.222
Agricultural training (yes=1)	484.802***	171.114	56.843	68.087
Household size (number)	-40.290***	8.877	13.107***	3.532
Social group (Disadvantaged section =1)	36.597***	6.841	-2.565	2.722
Membership in farmer organizations (yes=1)	210.315*	112.415	81.608*	44.731
Kisan credit card (yes=1)	376.692***	58.599	20.874	23.317
Soil Health Card (yes=1)	898.383***	237.309	130.964	94.427
Crop insurance (yes=1)	-1688.242***	107.947	74.921*	42.953
Expenditure on seeds (Rs/ha)	0.514	0.019	0.094***	0.008
Expenditure on irrigation (Rs/ ha)	0.051	0.013	0.025***	0.005
MSP awareness (aware=1)	445.673	43.639	7.291	17.364
Access to technical advisory (yes=1)	540.705	46.027	27.211	18.315
Constant	2768.342	417.535	-268.008	166.140
Breusch-Pagan test of independence: chi2(1) = 9.091, Pr = 0.002				

,, and *** indicates significance at 10, 5 and 1 per cent respectively*

Regulatory Mechanism of Biopesticides in Major Consuming Countries

The European Union (EU) has stringent regulations for biopesticides to safeguard human health and the environment. Biopesticides, governed by Regulation (EC) No 1107/2009, undergo rigorous assessment and approval by the European Food Safety Authority (EFSA) before being authorized for use. The regulatory framework also includes Directive 2009/128/EC, which advocates for Integrated Pest Management (IPM) and non-chemical alternatives, and Regulation (EC) No 396/2005, establishing maximum residue levels (MRLs) for pesticides in food and feed. The approval process for biopesticides involves manufacturers providing evidence of safety and efficacy, with the European Food Safety Authority evaluating the dossier and the European Commission making the final approval decision. Biopesticides have distinct data requirements compared to chemical pesticides, requiring specific studies to demonstrate their minimal risk to non-target organisms. Additionally, they undergo post-market monitoring to ensure ongoing safety compliance. Despite lower registration costs, the economic burden of biopesticides varies.

In regions like India and Brazil, lower costs and less stringent regulations may encourage local and small-scale manufacturers to participate in the biopesticide market. This could lead to indigenous innovation and economic growth in the agriculture sector if the demand for biopesticides increases. Conversely, the European Union's comprehensive regulations and lengthy testing processes may deter smaller businesses from entering the market, providing an advantage to larger companies. The differences in registration procedures and efficacy testing standards between regions present challenges for companies seeking to enter global markets. The United States, India, and Brazil have expedited registration processes, fostering a dynamic market with rapid product turnover. In contrast, the European Union's strict standards may impede biopesticide entry and innovation. These variations have economic implications for small-scale producers, particularly in India and Brazil, where lower costs and simplified registration procedures enable expanded biopesticide use and premium pricing due to reduced chemical content. Meanwhile, small-scale farmers in regions with strict regulations, such as the EU and China, may face challenges in using biopesticides. Despite this, benefits such as reduced chemical residue and minimal impact on beneficial organisms make biopesticides an attractive option[5][18][19].

India could benefit from implementing specific guidelines for biopesticides, similar to those used by the European Union and China, to streamline the registration process and ensure adherence to safety and efficacy standards. Adopting standardized labeling requirements, a tiered registration model, and aligning efficacy testing requirements with global best practices could enhance regulatory efficiency and ensure the safe and effective use of biopesticides in India.

IV. Conclusion

For more than 60 years, pesticides have been regarded as a rapid, convenient, and low-cost alternative for managing insect pests in agriculture in India. However, their indiscriminate use leads to environmental and health concerns. Biopesticides offer a pathway for farmers to shift from chemical pesticides toward more sustainable and environmentally friendly options. The biopesticides market in India is poised for rapid growth, driven by rising health and environmental concerns, technological advancements, and the increasing popularity of organic farming. While the market faces challenges such as technological limitations and a strong preference for chemical pesticides in some regions, its future looks promising. As opportunities exist through innovations in product formulation and application, positioning the biopesticides market as a vital component of sustainable agriculture is the need of the hour. For this intervention of the government through strong regulatory mechanisms and measures to support and promote biopesticide use is critical. It is recommended that the commercial and public sectors collaborate to support farmers at the grassroots level by developing an integrated policy and guidelines for the use of bio-pesticides and chemical pesticides.

Notes

JEL.: Q10, Q12, Q16

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