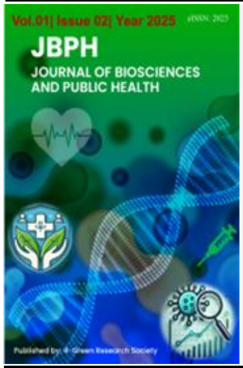

J. Biosci. Public Health **2025; 1(3):16-27**

JBPH

Open access

Journal of Biosciences and Public Health

eISSN: 3104-8749

DOI: https://doi.org/10.5455/JBPH.2025.12

Published by: www.4greenresearch.org

MINI-REVIEW ARTICLE

Pesticide-Associated Health and Environmental Risks and the Role of Biofertilizers in Sustainable Agriculture

Monish Kumar Roy[1,2], Sukumar Roy[2], Bissas Binduraz[2], Layba Afrin[2], Md. Azizul Haque[2,*]

[1]Department of Chemistry, Dinajpur Govt. College, Dinajpur-5200, Bangladesh

[2]Department of Biochemistry and Molecular Biology, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh

Article info
Received: September 16, 2025
Revised: September 20, 2025
Accepted: September 21, 2025
Published: September 24, 2025

***Corresponding author**
Department of Biochemistry and Molecular Biology, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh
E-mail: helalbmb2016@hstu.ac.bd
ORCID ID: https://orcid.org/0000-0002-9788-0766

Keywords: Pesticides contamination, Health risks, Food safety, Biofertilizers, Biopesticides, Bacterial biofertilizer, Soil fertility.

Cite this article: Roy MK, Roy S, Binduraz B, Afrin L, Haque MA. Pesticide-associated Health and Environmental Risks and the Potential of Biofertilizers in Sustainable Agriculture. *J Biosci Public Health.* 2025;1(3):16-27.

ABSTRACT

The cornerstone of the economy of Bangladesh is its agriculture, which relies heavily on synthetic pesticides and fertilizers to meet food demands for its 180 million population. However, this escalation has led to severe public health and environmental challenges. Pesticide misuse, coupled with inadequate safety measures and lax regulations, results in acute poisoning, chronic health issues like carcinogenesis, and ecological harm, including soil degradation and water contamination. Approximately 29% of vegetables in Bangladesh contain pesticide residues, with 73% exceeding safe limits, posing significant risks to consumers. Biofertilizers, utilizing beneficial microorganisms like Azotobacter and Rhizobium, offer a sustainable alternative by enhancing soil fertility, promoting plant growth, and reducing chemical dependency. This minireview focuses on the health and environmental impacts of pesticide overuse in Bangladesh and highlights the potential of biofertilizers to mitigate these risks, advocating for policy reforms, research, and awareness to ensure sustainable agriculture and public health safety.

1. INTRODUCTION

With nearly 40% of the workforce employed in agriculture and a 12.9% GDP contribution, it is the cornerstone of Bangladesh's economy [1]. A population of more than 180 million depends on the production of a variety of crops, including rice, vegetables, jute, tea, and fruits, which are made possible by the country's rich soils and temperate climate [2]. In 2022, farmers used 3.70 million tonnes of pesticides worldwide, 4% more than in 2021, 13% more than ten years ago, and double the amount used in 1990 [3]. Despite increasing crop yields, these chemical inputs cause serious risks to food safety, public health, and environmental sustainability [4]. Furthermore, 40% of fresh vegetables and 25% of rice samples in Bangladesh have been reported to exceed FAO/WHO maximum residue limits, which testifies to weak regulatory enforcement and low farmer knowledge on the safe handling of pesticides [5, 6]. Studies report that roughly 27% of farmers suffer from pesticide-related ailments, including acute poisoning, respiratory issues, and skin irritation, with chronic exposure linked to long-term illnesses like cancer, neurological damage, and endocrine disruption [7, 8]. The absence of proper safety measures, training, and equipment even exacerbates the scenario, causing harmful chemical residues of pesticides in food, water, and soil, posing a silent shocking health crisis for both farmers and consumers [9]. Environmental consequences include soil microbial degradation, water contamination, and loss of biodiversity, which further undermine agricultural sustainability [10]. Among these challenges, biofertilizers and biopesticides, which leverage beneficial microorganisms to enhance soil fertility, promote plant growth, and reduce reliance on chemical inputs, offer a promising, eco-friendly alternative [11, 12]. Biofertilizers, especially those incorporating plant growth-promoting rhizobacteria (PGPR), offer significant prospects as sustainable alternatives to synthetic pesticides by combining nutrient recycling with biocontrol properties that suppress plant pathogens and pests through mechanisms such as antibiosis, nutrient competition, siderophore production, and induced systemic resistance [13]. This dual functionality not only enhances crop productivity and soil fertility but also mitigates environmental risks like soil degradation, water contamination, and biodiversity loss associated with chemical pesticides, positioning biofertilizers as key players in integrated pest management for eco-friendly agriculture [14]. Complementarily, biopesticides encompassing microbial agents, phytopesticides, and nanobiopesticides provide targeted control of pests and pathogens through mechanisms like antibiosis and induced resistance, exhibiting low toxicity, biodegradability, and reduced risk of resistance development compared to conventional chemicals [15, 16]. However, challenges such as limited shelf life persist, necessitating further research and development to enhance stability and efficacy [17].

This minireview examines the scope of Bangladesh’s pesticide crisis, its detrimental impacts on human health and the environment, and the transformative potential of biofertilizers to ensure a safer, more sustainable agricultural future.

2. PESTICIDE EXPOSURE AND HUMAN HEALTH RISKS

2.1. Human Health Risks of Pesticide Use in Bangladesh

Pesticide use in Bangladesh poses significant health risks, including acute poisoning and long-term chronic effects, which are just two of the many negative health impacts of pesticide exposure. Agricultural workers and farmers are the most vulnerable group living at risk because they are directly exposed when handling, mixing, and spraying chemical fertilizer. However, consumers can also be inadvertently exposed by consuming tainted food or drink.

As shown in **Figure 1**, acute pesticide poisoning is quite frequent in the rural areas of Bangladesh. Headaches, nausea, vomiting, skin irritation, lightheadedness, blurred vision, and respiratory syndromes are the most common symptoms seen in the case of pesticide poisoning [18]. Those who are affected may not have access to instant medical attention in several cases, and official figures underreport the symptoms too. Besides, farmers' lack of knowledge about proper handling procedures and poor awareness make the situation worse. According to studies, a significant percentage of farmers in Bangladesh, while applying pesticides in the field, do not use gloves or masks [19].

Public health impacts from chronic chemical exposure can manifest years after the initial interaction, making it more pernicious. Carcinogenesis, neurotoxicity, endocrine disruption, reproductive abnormalities, and impaired child development have all been directly linked to long-term pesticide exposure [20]. For instance, learning disabilities and neurological impairments are associated with exposure to organophosphates, which are still in common use in Bangladesh. Khatun et al. [21] conducted a systematic review that found alarming levels of contamination in the food supply of Bangladesh: about 29% of vegetables, roughly, had pesticide residues, 73% of which exceeded international maximum residue limits (MRLs). A lot more vegetables harvested in our country and consumed are highly contaminated, e.g., tomato, cucumber, cauliflower, and eggfruit. Nevertheless, the regular uptake of these adulterated vegetables by our end-users is deteriorating their immunity by placing them into long-term health hazards. In addition, these findings are more consistent with previous research, which found the presence of residues of an alarming nineteen different pesticides in fresh vegetables from Bangladeshi markets [21, 22]. This finding has revealed the intensified risks of synergistic detrimental effects by conducting an assay of a number of residual presences in a single food sample. The dangers of contamination are exacerbated by dint of lacking enforcement and longer pesticide withdrawal timing, which escalates a systemic risk to public health in the long run.

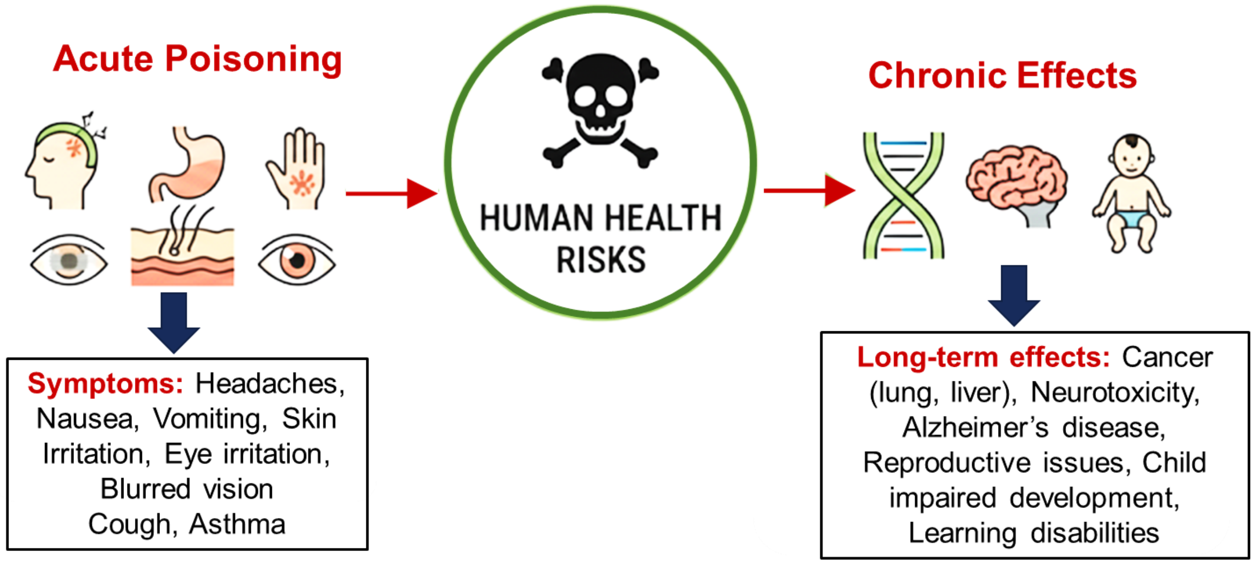

Figure 1. Pesticides exposure and human health risks.

2.2. Pesticide Exposure and Vulnerable Populations

Pesticide exposure poses significant health risks to vulnerable populations, including the elderly, women, and children, who are more susceptible due to physiological and socioeconomic factors. Children are particularly at risk because their developing detoxification systems are less efficient, and they consume higher amounts of fruits and vegetables relative to their body weight [23, 24]. Pregnant women face increased risks of adverse reproductive outcomes, such as miscarriage, low birth weight, and congenital anomalies, due to pesticide exposure [25, 26].

The elderly, with compromised immune systems and reduced metabolic capacity, are also highly vulnerable to the toxic effects of pesticides [27]. Additionally, low-income agricultural workers in Bangladesh, often residing near treated fields, face discriminating risks of household contamination through pesticide residues on clothing, agricultural tools, and environmental media such as water and air [28, 29]. These factors underscore that pesticide exposure in Bangladesh is a critical public health issue, extending beyond occupational hazards to impact rural and urban communities alike.

3. ENVIRONMENTAL CONSEQUENCES OF PESTICIDE OVERUSE

Figure 2 demonstrated the widespread and excessive use of pesticides in agriculture. They are employed to enhance crop yields by controlling pests, but their overuse has led to detrimental environmental and public health consequences. These include soil microbial degradation, water contamination, loss of biodiversity, and contributions to climate change. The following part explores briefly these environmental consequences to reduce pesticide dependence in Bangladesh.

3.1. Soil Microbial Degradation

The fragile equilibrium of soil microbiota, which is necessary for nitrogen fixation and organic matter biodegradation, becomes disrupted by pesticides. It has been demonstrated that the use of chemical pesticides, such as carbamates and organophosphates, lowers the number of helpful microorganisms like Azotobacter and Rhizobium, thereby lowering soil fertility [30, 31]. In order to make up for nutrient deficiencies, farmers are forced to use synthetic fertilizers, which causes the deterioration of soil health and raises agricultural expenses [32]. This eventually leads to a cycle of dependency that threatens environmentally friendly agricultural practices.

3.2. Water Contamination

Pesticide runoff during monsoon seasons contaminates rivers, canals, and groundwater systems, posing a significant threat to drinking water sources in Bangladesh. In flood-prone areas, where waterlogging is common, pesticide leaching into surface and groundwater is a critical issue [33]. Studies have detected high levels of pesticide residues, such as DDT and endosulfan, in water bodies across rural Bangladesh, leading to bioaccumulation in aquatic organisms and potential human exposure through the food chain [34, 35]. This contamination not only affects human health but also disrupts aquatic ecosystems, reducing fish populations vital for local livelihoods [36].

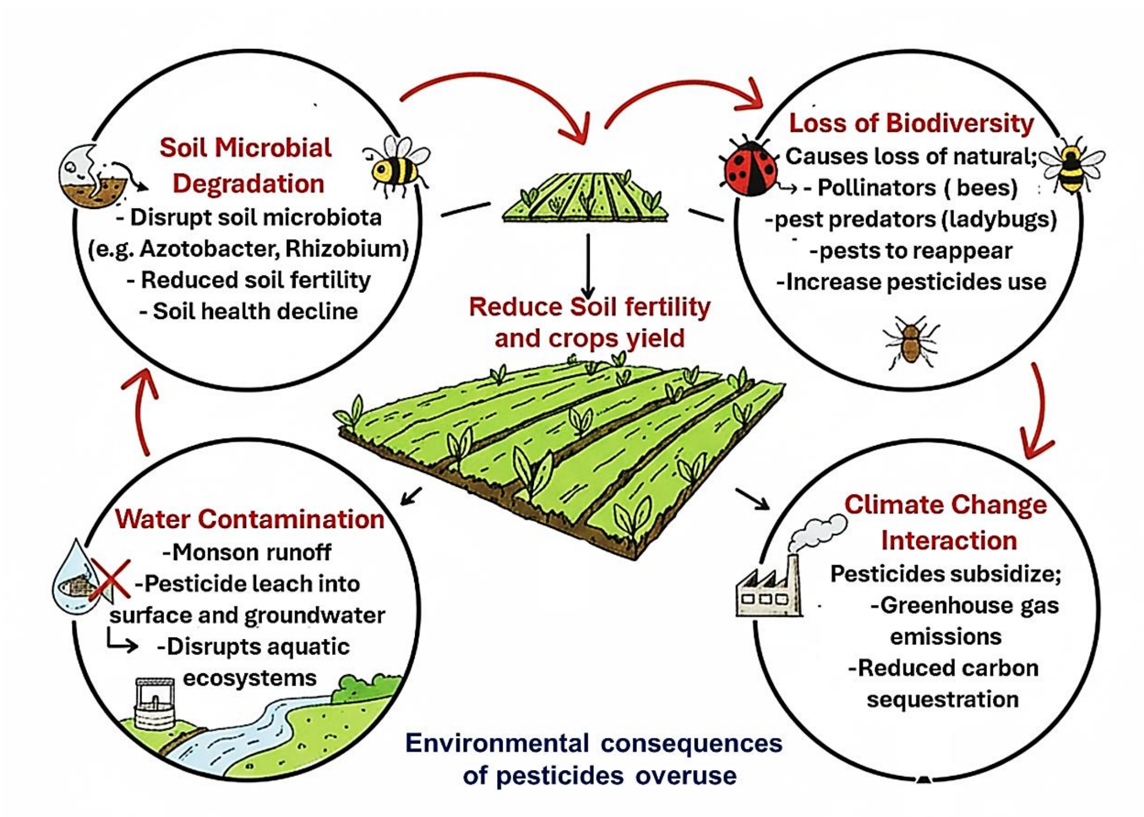

Figure 2. Impacts on the environments of pesticides overuse.

3.3. Loss of Biodiversity

Beneficial species, such as pollinators (like bees and butterflies) and natural pest predators (like ladybugs and spiders), are harmed by pesticides in ways that are not specific to their targets [37]. Food security is impacted by crop pollination disruptions caused by declining pollinator populations [38]. Furthermore, an ecological imbalance caused on by the loss of natural pest predators causes pests to reappear and necessitates the use of additional pesticides [39]. This vicious cycle raises farmers' financial burdens while sustaining environmental degradation.

3.4. Climate Change Interactions

The production, transportation, and application of pesticides contribute to greenhouse gas emissions, including carbon dioxide (CO_2) and nitrous oxide (N_2O) [40]. Moreover, pesticide-stressed soils exhibit reduced carbon sequestration capacity and release higher levels of CO_2 and N_2O, exacerbating climate change [41]. In Bangladesh, where agriculture is a significant contributor to the economy, the environmental footprint of pesticide use underscores the need for sustainable alternatives to mitigate climate impacts.

4. BIOFERTILIZERS AS A SUSTAINABLE ALTERNATIVE

A safer alternative to synthetic pesticides and fertilizers is a matter of prime concern to mitigate escalating public health risks and environmental damage. Biofertilizers, derived from beneficial microorganisms such as *Rhizobium*, *Azospirillum*, and *Bacillus*, provide a sustainable approach by enhancing soil fertility through nitrogen fixation, phosphorus solubilization, and plant growth promotion without the adverse environmental impacts of chemical inputs [42]. Numerous microorganisms, including *Klebsiella*, *Pseudomonas*, *Burkholderia*, *Acinetobacter*, *Serratia*, *Citrobacter*, *Enterobacter*, *Rhizobium*, *Azotobacter*, and *Azospirillum*, are known to fix atmospheric nitrogen into bioavailable forms within the plant root microbiome, thereby reducing dependence on synthetic nitrogen fertilizers [43]. For instance, *Azotobacter chroococcum* can fix 10 mgN/g of in-vitro provided carbon source, making it a suitable biofertilizate [44-48]. In addition, certain bacteria and fungi solubilize insoluble phosphates, improving phosphorus uptake by plant roots; since the 1950s, phosphorus-dissolving bacteria have been used as biofertilizers to convert soil phosphorus into plant-available forms [49]. Recent studies have identified several endophytic bacterial genera, including *Klebsiella*, *Pseudomonas*, *Burkholderia*, *Acinetobacter*, *Serratia*, *Citrobacter*, *Enterobacter*, and *Morganella*, isolated from rice, brinjal, and rhizospheric soils, as effective phosphate solubilizers [45-47]. Plant growth-promoting rhizobacteria (PGPR) also stimulate root hair and lateral root development through the production of phytohormones such as indole-3-acetic acid (IAA) [50], while some strains exhibit biocontrol properties by producing antimicrobial compounds, antibiotics, or by inducing systemic resistance in plants, thereby reducing disease incidence [46, 51]. Furthermore, certain bacterial strains enhance plant growth, such as *Ziziphus jujuba*, by elevating IAA and reducing abscisic acid (ABA) levels [52], and rhizospheric bacteria, PGPR, and phosphate-solubilizing bacteria (PSB) can produce secondary metabolites and alkaloids beneficial to plant health [53].

Biofertilizer-associated microbes also influence carbon fixation and modulate greenhouse gas emissions (CO_2, CH_4, N_2O), highlighting their role in sustainable agroecosystems [54]. As shown in **Figure 3**, list of endophytic bacteria capable of growing on minimal nutrient medium with diazinon as the sole carbon source promoted rice plant growth and yield in the absence of pesticide. These strains, isolated from the roots, shoots, and leaves of rice plants cultivated in Dinajpur, degraded both chlorpyrifos and diazinon into non-toxic compounds that served as carbon sources in vitro [50].

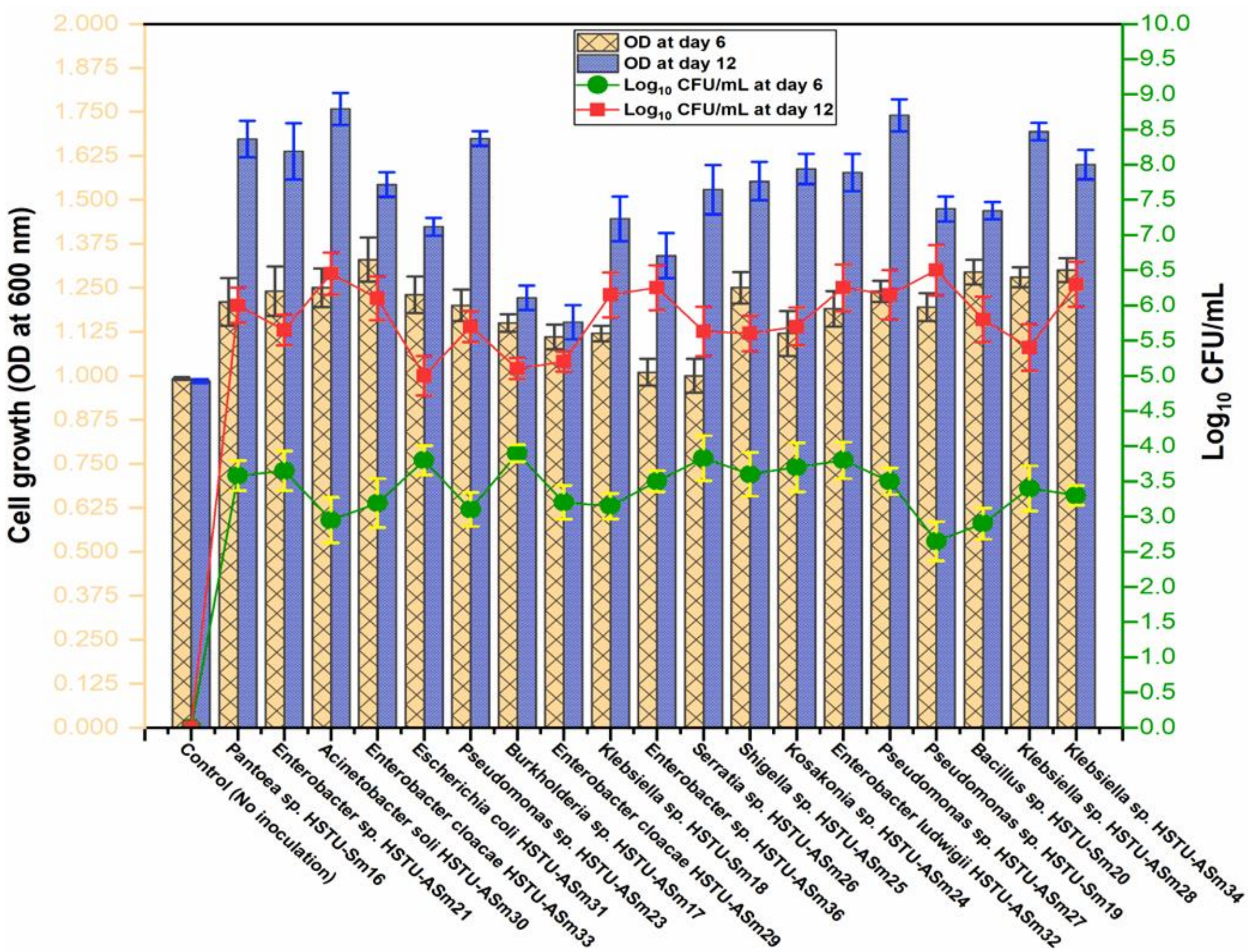

Figure 3. List of endophytic bacteria demonstrated their growth in minimal nutrient media where diazinon as the sole carbon sources and accelerated rice plants growth and yield promotion without any pesticide [50].

As illustrated in **Figure 4**, compared to chemical inputs, biofertilizers are non-toxic, safe for human health, cost-effective for farmers, and enhance soil fertility and structure over time. Recently, large-scale liquid cultures of biofertilizer-potential endophytic bacterial consortia have been developed in a biogrowth chamber for commercial applications [49].

Notably, biofertilizers have already been integrated into national agricultural strategies in countries such as China, India, and Nepal, where positive outcomes have been observed. In India, for example, nearly 25% less nitrogen fertilizer is required when widely used biofertilizers such as Azospirillum, Rhizobium, Azotobacter, Bacillus, and Pseudomonas are applied [49, 51]. Fungal biopesticides have shown similar results; in China, the use of mycorrhizal fungi during cultivation has improved crop resistance against drought stress [55].

These regional models could serve as valuable lessons for Bangladesh, where the adoption of biofertilizers remains relatively limited despite their significant potential. However, several challenges hinder their widespread use in Bangladesh, including nominal awareness among cultivators, insufficient production facilities, reluctant regulatory frameworks, and weak quality control mechanisms. To overcome these barriers, a coordinated multi-sectoral initiative is essential, focusing on financial assistance for biofertilizer production and marketing, enacting regulations to control import and sale, strengthening pesticide residue monitoring in the food market, expanding in-field microbial inoculant trials, and developing locally adapted PGPR and endophytic strains with plant growth-promoting and biodegradation traits. Moreover, the establishment of quality-assessment laboratories at public universities, improved agricultural extension services to reinforce integrated pest management (IPM) through combined use of biofertilizers and minimal chemicals, the creation of demonstration flag-plots in rural areas to build farmer confidence, and the promotion of biofertilizers in agribusiness through public-private partnerships and supply chain models are necessary steps to ensure successful adoption and long-term sustainability of biofertilizer use in Bangladesh.

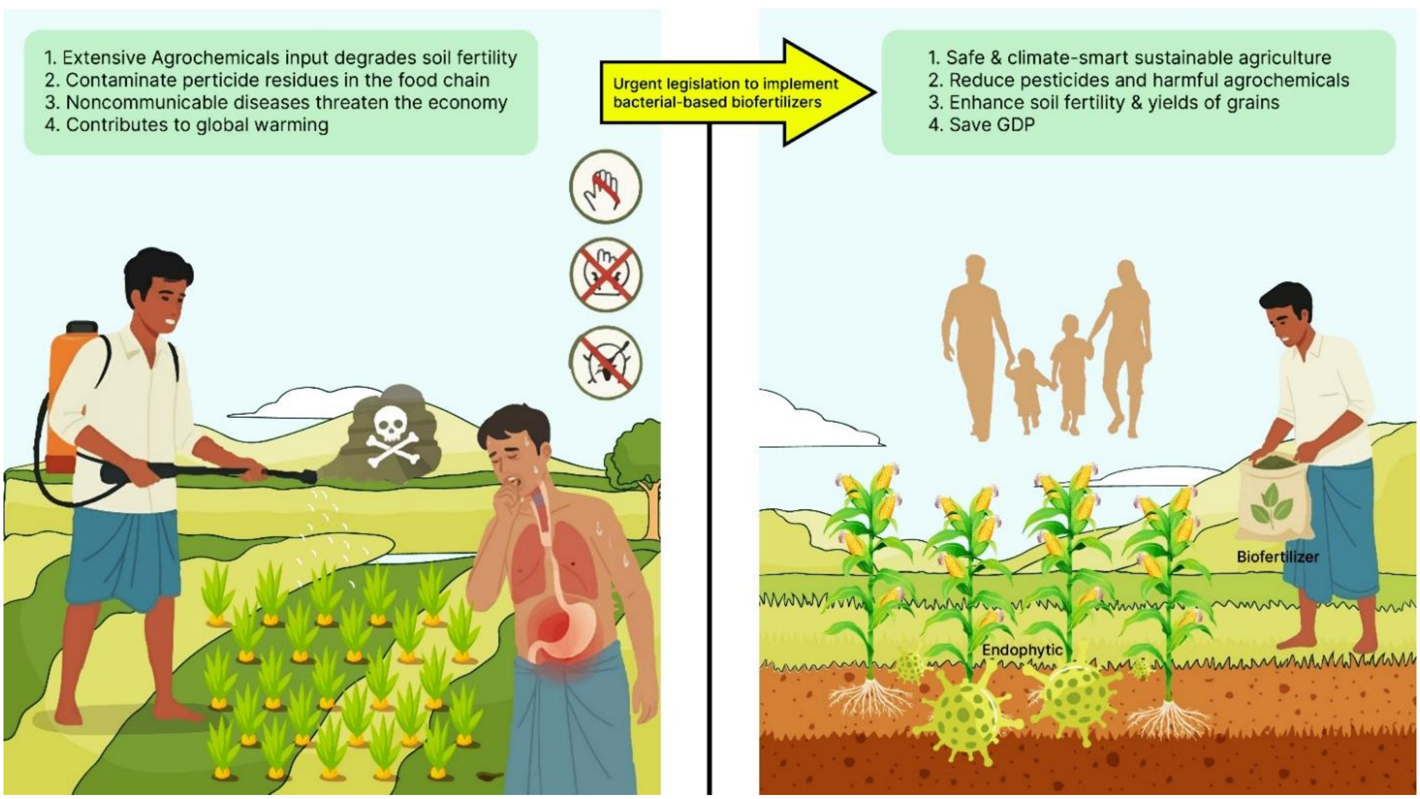

Figure 4. Schematic diagram of synthetic pesticides effects on human and environment and their mitigation approach with potential biofertilizers.

5. FUTURE PERSPECTIVES

Bangladesh faces dual challenges from the extensive use of chemical pesticides: a growing public health burden arising from pesticide exposure and harmful residues in food, and an environmental sustainability crisis caused by ecological contamination. Without timely intervention, the country risks accelerating environmental degradation and an increased prevalence of chronic diseases. Biofertilizers and biopesticides present eco-friendly, scientifically validated alternatives that support climate resilience, public health security, and sustainable agriculture, with several studies from public universities already highlighting their potential. To realize this paradigm shift, Bangladesh must prioritize investments in research, farmer education, public–private partnerships, and legislative reforms that facilitate large-scale biofertilizer adoption. In addition, requires a coherent national policy framework that ensures financial incentives for biofertilizer production and distribution, strict quality control standards, and effective regulatory oversight of imports and commercialization. By replacing harmful chemical inputs with natural alternatives such as biofertilizers, the nation can safeguard human health, restore ecological balance, and build resilient, sustainable, and safe food systems for the future.

6. CONCLUSIONS

Although extensive use of chemical fertilizers and pesticides has increased crop yields, there have been detrimental effects on the environment and human health. Widespread pesticide misuse has been shown to degrade soil fertility, contaminate water sources, reduce biodiversity, exacerbate the effects of climate change, and pose acute and long-term health risks to farmers, vulnerable populations, and consumers. Both the long-term viability of agriculture and public health are at risk due to these issues. An effective, environmentally responsible substitute is offered by biofertilizers and biopesticides. They can lessen reliance on dangerous chemicals, improve soil health, and encourage sustainable crop production by using beneficial microorganisms for nutrient cycling, growth promotion, and natural pest suppression. Other nations' experiences show that widespread use of biofertilizers is both practical and successful. For Bangladesh, realizing these benefits requires coordinated action: strengthening regulations and residue monitoring, investing in biofertilizer research and production, establishing quality-control laboratories, and expanding farmer education and demonstration programs. Promoting public–private partnerships and creating supportive policy frameworks will be essential to overcome current barriers. In summary, transitioning toward biofertilizer-based agriculture is critical to protect human health, ensure environmental sustainability, and secure resilient food systems in Bangladesh.

ACKNOWLEDGMENTS

We extend our heartfelt gratitude to all those who contributed to the successful completion of this research project.

FUNDING SOURCE

The study was conducted to fulfill an academic purpose. There were no funding sources available for this study.

CONFLICT OF INTEREST

The authors declare no conflict of interest. All aspects of this research were conducted impartially and independently. No financial or personal relationships with other people or organizations have influenced this work.

ETHICS STATEMENT

This study did not involve any experiments on human participants or animals; therefore, formal written informed consent was not required. All figures in this study were created with modifications based on relevant referenced sources; therefore, no permission for reuse is required for any figure presented herein.

REFERENCES

1. Carvalho FP. Pesticides, environment, and food safety. *Food Energy Secur.* 2017;6(2):48-60. doi:10.1002/fes3.108
2. Nicolopoulou-Stamati P, Maipas S, Kotampasi C, Stamatis P, Hens L. Chemical pesticides and human health: The urgent need for a new concept in agriculture. *Front Public Health.* 2016; 4:148. doi:10.3389/fpubh.2016.00148
3. Sharma A, Kumar V, Shahzad B, et al. Worldwide pesticide usage and its impacts on ecosystem. *SN Appl Sci.* 2019;1(11):1446. doi:10.1007/s42452-019-1485-1
4. Aktar MW, Sengupta D, Chowdhury A. Impact of pesticides use in agriculture: Their benefits and hazards. *Interdiscip Toxicol.* 2009;2(1):1-12. doi:10.2478/v10102-009-0001-7
5. Khatun P, Islam A, Sachi S, Islam MZ, Islam P. Pesticide exposure and health problems among female agricultural workers in Bangladesh. *Environ Sci Pollut Res.* 2023;30(14):40276-40287. doi:10.1007/s11356-022-24972-2
6. Chowdhury MAZ, Fakhruddin ANM, Islam MN, Moniruzzaman M, Gan SH, Alam MK. Detection of the residues of nineteen pesticides in fresh vegetable samples using gas chromatography–mass spectrometry. *Food Control.* 2013;34(2):457-465. doi: 10.1016/j.foodcont.2013.05.006
7. Mostafalou S, Abdollahi M. Pesticides and human chronic diseases: Evidences, mechanisms, and perspectives. *Toxicol Appl Pharmacol.* 2013;268(2):157-177. doi: 10.1016/j.taap.2013.01.025
8. Hossain MM, Rahman MA, Alam S. Pesticide use and its impact on health and environment in Bangladesh. *Int J Environ Monit Anal.* 2013;1(2):66-72. doi: 10.11648/j.ijema.20130102.15
9. Jørs E, Neupane D, London L. Pesticide poisonings in low- and middle-income countries. *Environ Health Insights.* 2018; 12:1178630217750876. doi:10.1177/1178630217750876
10. Hossain M, Rahman M. Pesticide consumption and productivity and food security: Empirical evidence from Bangladesh. *J Agric Rural Dev Trop Subtrop.* 2021;122(2):253-263. doi:10.17170/kobra-202110135010
11. Bashan Y, de-Bashan LE, Prabhu SR, Hernandez JP. Advances in plant growth-promoting bacterial inoculant technology: Formulations and practical perspectives (1998–2013). *Plant Soil.* 2014;378(1-2):1-33. doi:10.1007/s11104-013-1956-x
12. Vessey JK. Plant growth promoting rhizobacteria as biofertilizers. *Plant Soil.* 2003;255(2):571-586. doi:10.1023/A:1026037216893
13. Adesemoye AO, Torbert HA, Kloepper JW. Plant growth-promoting rhizobacteria allow reduced application rates of chemical fertilizers. *Microb Ecol.* 2009;58(4):921-929. doi:10.1007/s00248-009-9531-y
14. Backer R, Rokem JS, Ilangumaran G, et al. Plant growth-promoting rhizobacteria: Context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. *Front Plant Sci.* 2018; 9:1473. doi:10.3389/fpls.2018.01473
15. Koul O. Microbial biopesticides: Opportunities and challenges. *CAB Rev.* 2011;6(56):1-17. doi:10.1079/PAVSNNR20116056
16. Villaverde JJ, Sandín-España P, Sevilla-Morán B, López-Goti C, Alonso-Prados JL. Biopesticides in the framework of the European pesticide regulation (EC) No. 1107/2009. *Pest Manag Sci.* 2014;70(1):2-5. doi:10.1002/ps.3663

17. Arthurs S, Dara SK. Microbial biopesticides for integrated pest management. *Insect Biochem Mol Biol.* 2019; 106:1-10. doi: 10.1016/j.ibmb.2018.12.009

18. Mithu MMU, Shormela SA, Islam MS, Mubarak M. FTIR analysis of pesticide active ingredients into seasonal vegetables: Ensuring food safety and raising awareness. *J Glob Innov Agric Sci.* 2025; 13:139-147

19. Eskenazi B, Marks AR, Bradman A, et al. Organophosphate pesticide exposure and neurodevelopment in young Mexican-American children. *Environ Health Perspect.* 2007;115(5):792-798. doi:10.1289/ehp.9828

20. Roberts JR, Karr CJ; Council on Environmental Health. Pesticide exposure in children. *Pediatrics.* 2012;130(6): e1765-e1788. doi:10.1542/peds.2012-2584

21. Hanke W, Jurewicz J. The risk of adverse reproductive and developmental disorders due to occupational pesticide exposure: An overview of current epidemiological evidence. *Int J Occup Med Environ Health.* 2004;17(2):223-243.

22. Shirangi A, Nieuwenhuijsen M, Vienneau D, Holman CDJ. Living near agricultural pesticide applications and the risk of adverse reproductive outcomes: A review of the literature. *Paediatr Perinat Epidemiol.* 2011;25(2):172-191. doi:10.1111/j.1365-3016.2010. 01165.x

23. Geller AM, Zenick H. Aging and the environment: A research framework. *Environ Health Perspect.* 2005;113(9):1257-1262. doi:10.1289/ehp.7569

24. Hossain F, Ali O, D'Souza UJA, Naing DKS. Health risks of pesticide exposure among farmers in Bangladesh. *J Occup Health.* 2017;59(2):163-171. doi:10.1539/joh.16-0197-OA

25. Stadlinger N, Mmochi AJ, Kumblad L. Weak governmental institutions and indiscriminate use of pesticides in Bangladesh: Impacts on human health and environment. *Environ Dev.* 2011;8(1):10-22. doi: 10.1016/j.envdev.2011.07.002

26. Kumar S, Sharma AK, Rawat SS. Impact of pesticides on soil microbial diversity and activity. *J Environ Biol.* 2018;39(5):645-652. doi:10.22438/jeb/39/5/MRN-614

27. Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. Agricultural sustainability and intensive production practices. *Nature.* 2002;418(6898):671-677. doi:10.1038/nature01014

28. Matin MA, Islam MM, Hossain MI. Pesticide residues in surface and groundwater in Bangladesh: A review. *Environ Monit Assess.* 2020;192(6):364. doi:10.1007/s10661-020-08328-7

29. Chowdhury AZ, Jahan SA, Islam MN, et al. Occurrence of organochlorine pesticide residues in water and sediment samples from the haor region of Bangladesh. *Chemosphere.* 2012;87(5):531-538. doi: 10.1016/j.chemosphere.2011.12.058

30. Hasanuzzaman M, Rahman MA, Salam MA. Pesticide contamination in groundwater and its impact on human health in Bangladesh. *J Water Health.* 2017;15(6):885-893. doi:10.2166/wh.2017.008

31. Ali U, Syed JH, Malik RN, et al. Pesticides in the aquatic environment of Bangladesh: A review. *Environ Chem Lett.* 2014;12(2):241-256. doi:10.1007/s10311-013-0454-8

32. Desneux N, Decourtye A, Delpuech JM. The sublethal effects of pesticides on beneficial arthropods. *Annu Rev Entomol.* 2007; 52:81-106. doi: 10.1146/annurev.ento.52.110405.091440

33. Potts SG, Biesmeijer JC, Kremen C, et al. Global pollinator declines: Trends, impacts and drivers. *Trends Ecol Evol.* 2010;25(6):345-353. doi: 10.1016/j.tree.2010.01.007

34. Geiger F, Bengtsson J, Berendse F, et al. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Appl Ecol.* 2010;11(2):97-105. doi: 10.1016/j.baae.2009.12.001

35. Lal R. Soil carbon sequestration impacts on global climate change and food security. *Science.* 2004;304(5677):1623-1627. doi:10.1126/science.1097396

36. Zhang W, Ricketts TH, Kremen C, Carney K, Swinton SM. Ecosystem services and dis-services to agriculture. *Ecol Econ.* 2007;64(2):253-260. doi: 10.1016/j.ecolecon.2007.02.024

37. Zhao G, Li J, Wang X, et al. Development of biofertilizers for sustainable agriculture over four decades (1980–2022). *Geosustainability.* 2023;4(3):100029. doi: 10.1016/j.geosus.2023.09.006

38. Mukherjee A, Gaurav AK, Singh S, et al. The bioactive potential of phytohormones: A review. *Biotechnol Rep.* 2022;8: e00748. doi: 10.1016/j.btre. 2022.e00748

39. Sun B, Bai Z, Bao L, et al. Bacillus subtilis biofertilizer mitigating agricultural ammonia emission and shifting soil nitrogen cycling microbiomes. *Environ Int.* 2020; 144:105989. doi: 10.1016/j.envint.2020.105989

40. Qin Y, Hou J, Deng M, et al. Drought-tolerant plant growth-promoting rhizobacteria isolated from jujube (Ziziphus jujuba) and their potential to enhance drought tolerance. *Plant Soil.* 2020;452(1-2):423-440. doi:10.1007/s11104-020-04582-5

41. Prodhan MY, Rahman MB, Rahman A, et al. Characterization of growth-promoting activities of consortia of chlorpyrifos-mineralizing endophytic bacteria naturally harboring in rice plants. *Microorganisms.* 2023;11(7):1821. doi:10.3390/microorganisms11071821
42. Haque MA, Hossain MS, Ahmad I, et al. Unveiling chlorpyrifos mineralizing and tomato plant-growth activities of *Enterobacter* sp. strain HSTU-ASh6. *Front Microbiol.* 2022; 13:1060554. doi:10.3389/fmicb.2022.1060554
43. Wang X, Xie H, Ku Y, et al. Chemotaxis of *Bacillus cereus* YL6 and its colonization of Chinese cabbage seedlings. *Plant Soil.* 2020;447(1-2):413-430. doi:10.1007/s11104-019-04344-y
44. Aloo BN, Tripathi V, Makumba BA, Mbega ER. Plant growth-promoting rhizobacterial biofertilizers for crop production: The past, present, and future. *Front Plant Sci.* 2022; 13:1002448. doi:10.3389/fpls.2022.1002448
45. Kefi A, Ben Slimene I, Karkouch I, et al. Characterization of endophytic *Bacillus* strains from tomato plants displaying antifungal activity against *Botrytis cinerea*. *World J Microbiol Biotechnol.* 2015;31(12):1967-1976. doi:10.1007/s11274-015-1945-6
46. Das SR, Haque MA, Akbor MA, et al. Organophosphorus insecticides mineralizing endophytic and rhizospheric soil bacterial consortium influence eggplant growth-promotion. *Arch Microbiol.* 2022;204(11):199. doi:10.1007/s00203-022-03185-2
47. Cho DY, Jang MY, Lee HY, et al. Rhizospheric bacterial distribution influencing enrichment of isoflavones, phenolics, flavonoids and antioxidant activity in soybean roots. *Plants (Basel).* 2025;14(14):2238. doi:10.3390/plants14142238
48. Cheng X, Wang G, Zhou Y, et al. Biofertilizer outcompetes chemical fertilizer in enhancing carbon sequestration in Moso bamboo forests. *Ind Crops Prod.* 2025; 232:121244. doi: 10.1016/j.indcrop.2025.121244
49. Ahmed T, Rahman MS, Rokanuzzaman, et al. Utilization of endophytic bacteria for liquid biofertilizer production with a newly designed prototype fermentor for plant improvement. *Plant Trends.* 2024;2(4):92-107. doi:10.5455/pt.2024.08
50. Haque MA, Simo T, Prodhan MY, et al. Enhanced rice plant (BRRI-28) growth at lower doses of urea caused by diazinon-mineralizing endophytic bacterial consortia. *Arch Microbiol.* 2023;205(6):231. doi:10.1007/s00203-023-03564-2
51. Ahmad MF, Ahmad FA, Alsayegh AA, et al. Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures. *Heliyon.* 2024;10(7): e29128. doi: 10.1016/j.heliyon.2024.e29128
52. Dlamini WN, Lai WA, Chen WC, Shen FT. Unveiling the Thermotolerance and Growth-Promoting Attributes of Endophytic Bacteria Derived from *Oryza sativa*: Implications for Sustainable Agriculture. Microorganisms. 2025 Mar 27;13(4):766. doi: 10.3390/microorganisms13040766.
53. Bouremani N, Cherif-Silini H, Silini A, Bouket AC, Luptakova L, Alenezi FN, Baranov O, Belbahri L. Plant Growth-Promoting Rhizobacteria (PGPR): A Rampart against the Adverse Effects of Drought Stress. *Water*. 2023; 15(3):418. https://doi.org/10.3390/w15030418
54. Liu Y, Liang F, Yan S, et al. Optimizing fertilization strategies for low-carbon agriculture: Balancing greenhouse gas mitigation, soil health, and productivity. Results Eng. 2025; 27:107094. doi: 10.1016/j.rineng.2025.107094
55. Tang H, Hassan MU, Feng L, Nawaz M, Shah AN, Qari SH, Liu Y, Miao J. The Critical Role of Arbuscular Mycorrhizal Fungi to Improve Drought Tolerance and Nitrogen Use Efficiency in Crops. Front Plant Sci. 2022 Jul 6; 13:919166. doi: 10.3389/fpls.2022.919166.