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Review Paper

A Concurrent Review on Plant Derived Biopesticides and Synthetic Pesticides: Their Importance in Plant Protection and Impacts on Human Health

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Abstract: This review explores the impacts of synthetic pesticides and Biopesticides on human health, aiming to provide a comprehensive understanding of their benefits and risks. Currently, farmers are using synthetic pesticides to increase the yield of crop production, but they pose significant health risks, such as acute poisoning, cancer, endocrine disruption, anaphylactic shock and other severe health issues. On the other hand, Biopesticides, derived from natural organisms or plant-derived secondary metabolites, are considered safer alternatives, offering effective pest management with reduced risk to human health. This review draws attention to plant-derived material use in pest control management. Further, deciphering plant diseases with phytogenic bacteria and their control by organic bio-pesticide. Conclusively, this review suggests that future research should focus on integrated pest management approaches that combine the strengths of both synthetic and biopesticides applications while mitigating health risks. The findings underscore the imperative for ongoing evaluation of pesticide usage and provide a framework for informed decision-making regarding human exposure to these substances.

Key Words	Plant Protection, Synthetic pesticides, Biopesticides, Solanaceae family plants, Human health
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1.

Introduction

The significant effects of synthetics pesticides and biopesticides on human health, emphasizing the critical need for a nuanced understanding of their respective benefits and risks. The use of synthetic pesticides remains prevalent in modern agriculture. This review aims to explore the potential impact of synthetics pesticides on human health and surrounding environments. To improve the production yield, humans are increasing the utilization of synthetic pesticides day by day which leads to generate new diseases in humans after log use. Recent statistics indicating that around 2.5 million tons of chemicals pesticide are applied annually worldwide, reflecting their continued reliance for effective pest control and increased crop yields (Massawe et al., 2018).. While Agriculture serves as the backbone of the Indian economy, accounting for 18% of the total Gross Domestic Product (GDP) and employing approximately 45% of the population. Ensuring food security for over 1.27 billion residents in the face of diminishing arable land presents a significant challenge (Reddy et al., 2021). However, the associated health risks cannot be ignored; For example, exposure to synthetic pesticides has been linked to range of acute and chronic health issues, including acute poisoning, certain types of cancer, endocrine disruption, and severe allergic reactions such as anaphylactic shock. Prenatal exposure of mother or father to synthetic pesticides, exposure of children and young adults to synthetic chemical pesticides could increase the pesticide risks. Pesticide exposures have been correlated to several human diseases such as Parkinson's disease (PD), amyotrophic lateral sclerosis, Alzheimer's disease, asthma, bronchitis, infertility, congenital anomaly, attention deficit hyperactivity disorder, minimal brain disorder, autism, diabetes, and obesity, respiratory diseases, organ diseases and system failures etc. Recent studies have revealed concerning data about the health impacts of synthetic pesticide exposure. Researchers have found that agricultural workers exposed to these chemicals experience a considerably higher incidence of various health issues, such as neurological disorders and different cancer types, particularly non-Hodgkin lymphoma and leukemia. Moreover, the disruption of endocrine function, which can influence reproductive health and developmental processes, has surfaced as a significant public health issue associated with specific pesticides. These findings highlight the necessity of understanding not only the effectiveness of these products but also their broader effects on human health and environmental sustainability. These concerns have spurred heightened scrutiny from both researchers and regulatory authorities, further underscoring the urgency for investigating safer, alternative pest management strategies that could mitigate these severe health risks while sustaining agriculture productivity (Pergner and Lippert, 2023). On the other hand, Biopesticides offer a promising alternative to synthetic options; derived from natural organisms or plant-based derivatives. Biopesticides are considered to be significantly safer for human health and environments (Hao et al., 2024). They function through various mechanisms, such as plant defenses, plant growth stimulator, protect from bacterial and fungus infections including most destructive pathogens such as *Xanthomonas* species, *Ralstonia solanacearum, Agrobacterium tumefaciens, Pseudomonas syringae, Erwinia amylovora, Xylella fastidiosa, Dickeya* (*dadantii and solani*) *Pectobacterium carotovorum etc.* Biopesticides such as plant derived materials, phyto extracts and microbial biopesticides, antagonistic microorganisms, biochemical pesticides etc could be useful for control and management of plant diseases. Furthermore, biopesticides can enhance the sustainability of agricultural practices by promoting soil health and biodiversity, aligning with the principles of integrated pest management (IPM). Comparative analyses in recent studies have begun to elucidate the mechanisms by which synthetic pesticides and biopesticides function. Synthetic pesticides typically target specific physiological pathways in pests, resulting in rapid pest elimination but potentially causing toxicity in non-target organisms, including humans. Conversely, biopesticides generally utilize environmentally sustainable modes of action, such as competitive exclusion and the induction of pathogen resistance, providing a dual advantage of effective pest control alongside diminished toxicity and selectively killing targeted pathogens and pests by multiple modes of action. This comparison underscores the critical need for systematic assessments of these agents in relation to their efficacy in pest management and their associated health risks. In conclusion, the findings of this review highlight the necessity for ongoing assessment and informed decision-making regarding pesticide application in agriculture. It is crucial to establish frameworks that prioritize the protection of human health while addressing the complexities of pest management. As agricultural methodologies continue to advance, the incorporation of biopesticides into pest management strategies represents a vital opportunity to reduce health risks linked to synthetic pesticide use, ultimately promoting a safer and more sustainable agricultural landscape.

2. Plant diseases

Bacterial infections, caused by various pathogens such as *Xanthomonas spp., Pseudomonas spp., Ralstonia solanacearum* etc. pose severe threats to major crops including vegetables such as tomatoes, potatoes, cabbage, cauliflower, fruits, cereals and fiber crops such as cotton. These diseases often lead to wilting, rotting, and stunted growth, resulting in substantial economic losses for farmers and the agricultural sector as a whole. The increasing prevalence of bacterial resistance to conventional pesticides further complicates management strategies, prompting researchers and practitioners to seek alternative solutions. Extensive crop losses were caused by phytopathogenic bacteria belonging to more than 25 genera and over 200 species(Sharma et al., 2022). The most important plant pathogenic bacteria genera are *Pseudomonas, Ralstonia, Agrobacterium, Xanthomonas, Erwinia* (*Pantoea*), *Xylella, Pectobacter and Dickeya*(Buttimer et al., 2017; Mansfield et al., 2012). For example, few common infections in cotton plant such as bacterial blight of cotton, black arm of cotton and angular leaf spot of cotton caused by *Xanthomonas citri pv malvacearum* beside the fusarium wilt of cotton, caused by *Fusarium oxysporum f. sp. vasinfectom* which leads to lesser production of cotton worldwide (Cox Jr et al., 2019). A few decades back in 1996, Eastern Georgia (USA), causative agent of internal lint rot of cotton, *Pantoea agglomerans*, a bacterial pathogen was identified. Bacterial pathogens causing boll rot of cotton in India were *Pantoea agglomerans, Pantoea anthophila, Pseudomonas aeruginosa and Xanthomonas citri pv malvacearum*. Bacterial wilt or Southern bacterial blight is a major destructive disease caused by *Ralstonia solanacearum* in tomatoes, potatoes and Solanaceae plants. *R. solanacearum* is a devastating pathogen with a dramatic economic impact worldwide(Kumar et al., 2022a). *Ralstonia solanacearum* is the causative agent of bacterial wilt and infects over 200 plant species in 50 families(Xue et al., 2020). Bacterial spot of tomato and pepper is a destructive disease caused by four distinct devastating *Xanthomonas pathovars, Xanthomonas vesicatoria, X. euvesicatoria pv. euvesicatoria* (Xee), *X. euvesicatoria pv. perforans* (Xep) and *X. hortorum pv. gardneri* (Xhg) (Osdaghi et al., 2021). Bacterial canker of tomato is caused by a Gram positive actinobacterium, *Clavibacter michiganensis*. It causes unilateral wilt, marginal leaf necrosis, stem cankers, bird's eye lesions on fruits and ultimately plant death. causing economically challenging problem for tomato growers worldwide(Peritore-Galve et al., 2021). Bacterial speck disease of tomato caused by *Pseudomonas syringe pv tomato* is another most widespread disease-causing huge crop losses of tomato (El-Fatah et al., 2023). Black rot caused by the bacterium *Xanthomonas campestris pv. campestri*s (Xcc), is the most common and destructive seed borne bacterial disease of the cabbage family worldwide(Sumi et al., 2022). In cabbage and cauliflower losses due to black rot disease range from 50–70%. *Pectobacterium carotovorum* subsp. carotovorum (Pcc) (synonym *Erwinia carotovorum*) is a causative agent of soil-borne soft rot, in a broad range of vegetables such as cabbage, tomato, potato, cucumber and in flowering plants such as *Amorphophallus konjac*, and *Zantedeschia hybrida* (Cui et al., 2019). Bacterial leaf spot caused by *Pseudomonas syringae pv. maculicola* (Psm) occurs globally in at least 25 plants of crucifers including cabbage and cauliflower (Peters et al., 2004). The details bacterial plants diseases and associated bacterial phytopathogen are summarized in **Table 1.**

Table 1: Various bacterial phytopathogens and diseases caused by them in crop plants

Bacterial phytopathogen	Disease	Crop plant	Ref.
Xanthomonas campestris pv. campestris	Black rot	Cabbage, cauliflower, brussels sprouts, broccoli, Rape seed (canola), mustard, radish, and turnip.	(Ferby et al., 2024)
Xanthomonas campestris pv. vesicatoria	Bacterial leaf spot	Pepper, Tomato	(Otten and Büttner, 2021)
Xanthomonas citri pv. malvacearum	Bacterial blight of cotton, angular leaf spot of cotton, black arm of cotton, boll rot of cotton	Cotton	(Naqvi et al., 2022)
Xanthomonas citri pv. viticola	Grapevine bacterial canker	Grapes	(Ferreira et al., 2019b)
Xanthomonas oryzae pv. oryzae	Bacterial blight of rice	Rice	(Zhong et al., 2024b)
Xanthomonas oryzae pv. oryzicola	Bacterial leaf streak of rice	Rice	(Yang et al., 2023)
Xanthomonas euvesicatoria	Bacterial spot disease	Pepper, Tomato	(Hernández-Huerta et al., 2021; Potnis et al., 2015)
Xanthomonas hortorum gardneri	Bacterial spot disease	Pepper, Tomato	(Bernal et al., 2021b)
Xanthomonas fragariae	Bacterial angular leaf spot	Strawberry	(Turechek et al., 2023a)
Xanthomonas citri pv. punicae	Bacterial blight of pomegranate	Pomegranate	(Radhika et al., 2021a)
Xanthomonas citri pv. mangiferae indicae	Bacterial black spot	Mango	(Liu et al., 2023a)
Xanthomonas citri pv. fuscans	Bacterial blight of bean	Bean	(de Paiva et al., 2020b)
Xanthomonas campestris pv. raphani (Xanthomonas campestris pv armoraciae)	Bacterial leaf spot	Radish, turnip	(Fujikawa and Inoue, 2020a)
Xanthomonas arboricola pv. juglandis	Walnut blight	Walnut	(Kim et al., 2021a)
Xanthomonas arboricola pv. pruni,	Bacterial spot of stone fruits and almond	apricot, peach, nectarine, plum and almond	(Garita-Cambronero et al., 2018)
Xanthomonas albilineans	Leaf scald of sugar cane	Sugar cane	(Bini et al., 2023a)
Xanthomonas axonopodis pv. glycines	bacterial pustule disease in soybeans	Soybeans	(Li et al., 2022b)

Xanthomonas campestris pv. musacearum	Enset wilt, Banana bacterial wilt	Banana	(Nakato et al., 2019)
Xanthomonas translucens pv. translucens	Leaf streak of Barley	Barley	(Sapkota et al., 2020a)
Xanthomonas transluscens pv. cerealis	Leaf streak of wheat, barley	Wheat, Barley	(Shah et al., 2019b)
Xanthomonas vasicola pv. vasc ulorum	Bacterial leaf streak of corn	Corn	(Ortiz-Castro et al., 2020)
Xanthomonas cassavae	Cassava bacterial necrosis	Cassava	(Zárate-Chaves et al., 2021)
Xanthomonas oryzae pv. leersiae	Streak disease	Rice, gross	(Lang et al., 2019)
Xanthomonas oryzae pv.oryzicola	Streak disease	Rice	(Tall et al., 2022b)
Pseudomonas syringae pv. syringae	Speak, fleck, spot, blight, and canker diseases	Peach, stone fruit, lemon, kiwi, bean, sweet cherry, apricot, and rose	(Pinheiro et al., 2019)
Pseudomonas syringae pv. actinidiae	Bacterial canker of kiwi fruit	Kiwi fruit	(Vandelle et al., 2021)
Pseudomonas syringae pv. aesculi	Horse chestnut bleeding canker	horse chestnut	(James et al., 2020)
Pseudomonas syringae. pv. aptata	Leaf spot disease of beet	Beet	(Nikolić et al., 2023)
Pseudomonas syringae pv. atrofaciens	glume rot of wheat	Wheat	(Butsenko et al., 2020)

3. Pesticide:

According to Robert Finger, pesticides are chemical substances or biological agents designed to prevent, destroy, or control pests that harm crops, livestock, and human health. Pests can include insects, weeds, fungi, bacteria, and other organisms that compete with crops or pose health risks. Pesticides work by targeting specific biological processes in these pests, leading to their elimination or suppression(Finger, 2024).

4. Types of Pesticides:

The pesticides are classified into major categories such as insecticides, herbicides, fungicides, bactericides, and rodenticides. This review article explores the use of bactericides in pest control. Bactericides, which manage bacterial pathogens, are divided into two major categories: synthetic pesticides and Biopesticides i.e., explained below.

4.1 Synthetic Pesticide:

Synthetic pesticides are chemically manufactured substances designed to prevent, destroy, or control pests that can harm crops or human health. Unlike natural pesticides derived from plants or minerals, synthetic pesticides are typically created in laboratories and often exhibit higher potency and specificity in their action. An example of a synthetic pesticide is glyphosate, widely used in agriculture for weed control. It is an herbicide that targets specific enzymes in plants, thus inhibiting their growth without affecting most crops. In agriculture, synthetic pesticides play a critical role in enhancing crop yields and protecting food production systems (Cheng, 1990).They have significantly increased agricultural productivity by efficiently controlling a wide range of pests, including insects, weeds, and diseases, which can otherwise devastate crops. The use of these chemicals allows farmers to maintain healthy crops and secure food supply chains, thus contributing to global food security.

4.2 Biopesticides:

Biopesticides are natural products derived from living organisms, including plants, bacteria, fungi, and other microorganisms, designed to control pests. Biopesticides could mean living organisms (bacteria, Fungi, protozoa, viruses, and algae), their products (bio-chemicals produced by them) and also plant byproducts. EPA recognizes three categories of Biopesticides. These are microbial pesticides, plant incorporated protectants, biochemical pesticides. They are recognized for their effectiveness in pest management and are considered environmentally friendly alternatives to synthetic pesticides. A well known example of a biopesicide is the bacteria, *Bacillus thuringiensis* (Bt) which may infect insects of Lepidoptera, Coleoptera and Diptera. *Bacillus thuringiensis* (Bt), a soil-dwelling bacterium that produces toxins lethal to specific insects. Bt is widely used to protect crops such as cotton and corn from pest infestations (Barssoum et al., 2023). These are naturally produced biochemical materials basically non-toxic to the environment that can be employed in pest control. The biopesticides would be more effective when it formulates in nano size range for all the plant cells (Kumar et al., 2024b; Maurya et al., 2022a; Maurya et al., 2022b; Sharma et al., 2020; Srivastava et al., 2021b).

4.3 Nano-Synthetic Pesticides:

Nano-pesticides refer to pesticides that contain chemicals in nanoscale materials or nanoparticles. Those materials have specific characteristics, such as size and shape, and are designed with ideal and unique physical, chemical and biological properties. Nano-pesticides are pesticides formulated in nanomaterials fixed on a hybrid substrate, encapsulated in a matrix or functionalized nano carriers. Nano-agrochemicals (NACs) are nanomaterials and formulations specifically designed and controlled at the nanoscale(Chaud et al., 2021).The U.S. Environmental Protection Agency (EPA) proposed that size of nano-pesticides should be in the size range of 1 to 100 nm. Some authors suggested that the particle size of nano-pesticides should be lesser than 500 or 1000 nm (Shangguan et al., 2024). The European commission defined nano-pesticides as a natural, incidental, or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm. Nano-pesticides as nano particles are now produced and used as novel carriers for the delivery of pesticides. Different types of formulation suggested include nano-emulsions, nano-encapsulations, nano-vesicles, nano-fibers etc. are used to improve efficacy of existing pesticides. Nano pesticides may be either nano based synthetic pesticides or Nano-biopesticides (Abdollahdokht et al., 2022).

4.4 Nano-biopesticides:

Nano-biopesticides derived from plant materials represent a promising advancement in pest control, offering an environmentally friendly alternative to traditional chemical pesticides. Additionally, it could be analyzed by HPLC, LCMS and different types of analytical methods. (Kumar et al., 2024a; Maurya et al., 2021; Rana et al., 2024). These biopesticides utilize nanoparticles to improve the efficacy and delivery of active compounds while reducing the environmental impact associated with chemical pesticides (**Figure 1**). It could be used for plant growth stimulator for plants and therapeutics management for cancer or metabolic diseases(Kumar et al., 2022b). The incorporation of nanotechnology allows for enhanced targeting and controlled release of biocontrol agents, contributing to the sustainability of agricultural practices. Research indicates that various plant species can yield nanoparticles, further supporting the development of effective pest management solutions. Overall, the potential of plant-derived nano-biopesticides is significant for sustainable agriculture(Krishnamurthy et al., 2020). Nano based biopesticide formulations such liposomes micelles, nano-emulsion, nanoparticle, and mesoporous etc., could be delivered active lead compounds inside the plant cells easily compared to other conventional formulations(Kumar et al., 2025; Sharma et al.; Srivastava et al., 2021a).

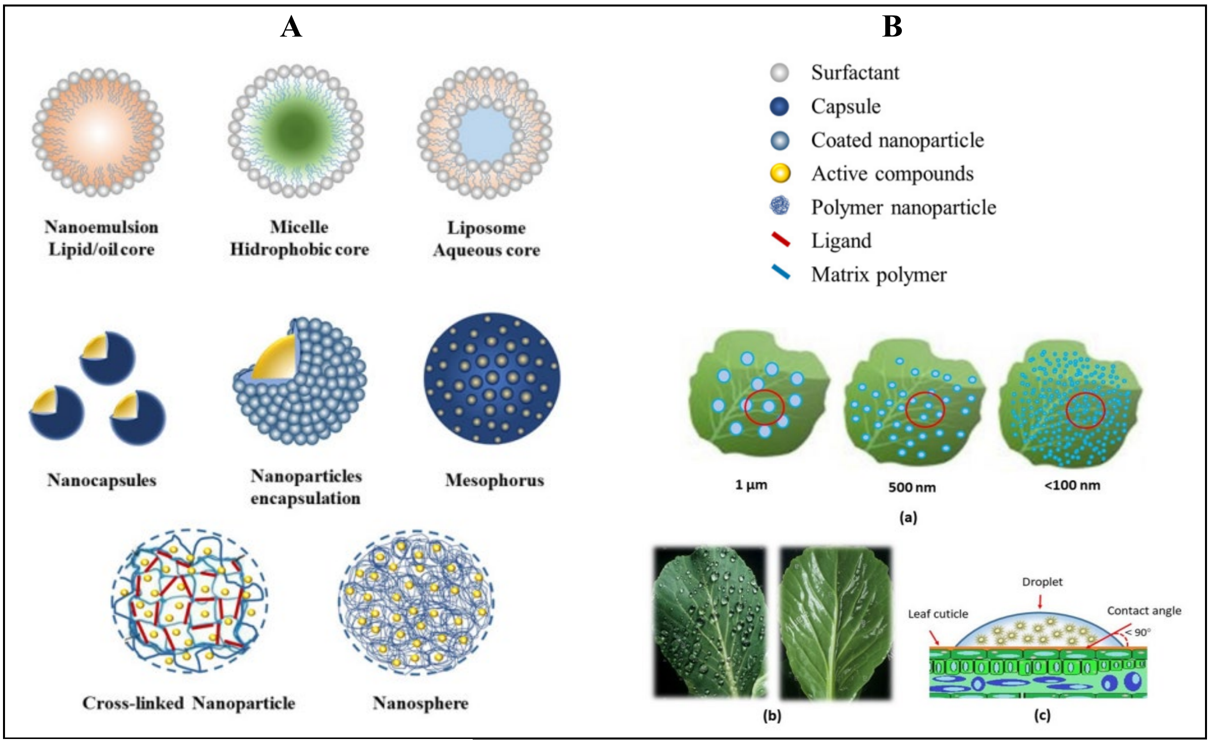

Figure 1: (A) Various types of nano -delivery biopesticide formulations could be prepared for the protection of plant diseases (B) An illustration depicting the distribution of droplets containing a nano-delivery system based on droplet size and the wettability of the leaf surface (a); a comparative image showing nanomicelle droplets with low wettability (left) and high wettability (right) on the leaf surface (b); and a representation of the reduction in surface tension in droplets containing a nano-sized suspension on the leaf surface (< 90° C). CC by 4.0, (Melanie et al., 2022; Sharma et al., 2020)

5. Protection of Plant diseases:

Protection of plants from bacterial infections is an essential aspect of modern agriculture, as these diseases can significantly affect crop yield and food security. Efforts to manage bacterial plant diseases have evolved, focusing on integrated approaches that combine chemical, biological, and cultural practices to enhance plant health and minimize disease incidence (Maciag et al., 2023).

5.1 Biological Control Strategies:

Biological control is a promising alternative to synthetic pesticides for managing bacterial diseases. Utilizing naturally occurring microorganisms and plants derived biomaterial as biocontrol agents has gained traction in recent years. Beneficial bacteria, such as *Bacillus subtilis* and *Pseudomonas fluorescens*, are known for their ability to inhibit plant pathogens through competition, secretion of antimicrobial compounds, and induction of plant defenses (Morikawa, 2006). These biocontrol agents enhance crop resilience and reduce disease incidence, providing an eco-friendly approach to pest management. Plant growth-promoting rhizobacteria (PGPR) is particularly effective in promoting plant health. PGPR can enhance nutrient uptake, stimulate root development, and induce systemic resistance in plants, thereby improving their capacity to combat bacterial infections. Research shows that the application of PGPR not only suppresses pathogen growth but also promotes overall plant vitality and yield(Bonaterra et al., 2022b).

5.2 Integrated Disease Management:

An integrated approach to managing bacterial diseases involves combining biological control with other practices such as crop rotation, the use of resistant crop varieties, and cultural practices that optimize plant health. Crop rotation helps to disrupt the life cycles of pathogens and reduces their population in the soil. Additionally, the selection of resistant plant varieties is a crucial component of a comprehensive disease management strategy, offering a sustainable solution to bacterial infections(Sundin et al., 2016).

5.3 Synthetic pesticides approach:

The protection of plants from bacterial infections using synthetic pesticides has been a common practice in agriculture. Synthetic pesticides are effective at controlling a range of bacterial pathogens, such as *Ralstonia solanacearum*, which causes wilt disease in crops like tomatoes. However, the reliance on these chemicals raises concerns regarding environmental impact and the development of resistance in pathogens, leading to decreased efficacy over time (Ayilara et al., 2023).

5.4 Biopesticides pest control approach

The protection of plants from bacterial infections using biopesticides is an effective and environmentally friendly approach in agricultural practices(Higgins et al., 2024). Biopesticides, which include beneficial microorganisms and natural substances, enhance plant health and suppress pathogens without the harmful effects associated with synthetic chemicals. One notable example is the use of *Bacillus subtilis*, a beneficial *bacterium* that acts as a biocontrol agent against various bacterial diseases(Habazar et al., 2018; Higgins et al., 2024). The details Summary of plant diseases and causative bacterial pathogens and pest control managements are reported in **Table 2.**

5.5 Microbial Biopesticides:

Microbial pesticides, Plant incorporated protectants, Biochemical pesticides. Biological control is an effective strategy and sustainable alternative method or supplement to conventional chemical pesticides for microbial plant disease management. Several research studies show the role of beneficial bacteria in promoting plant growth and disease resistance and disease control in crops. Bacteria strains belonging to *Bacillus, Paenibacillus, Agrobacterium, Bradyrhizobium, Acinetobacter, Azospirillum, Azotobacter, Pseudomonas, Rhizobium and Streptomyces,* have been reported as biocontrol agents for control and management of various diseases in major crops(Ayaz et al., 2021; Massawe et al., 2018). Some of the most intensively studied are bacteria belonging of the genus *Pseudomonas spp., Bacillus spp., and Streptomyces spp.,* that have been already registered as commercial products and marketed. Nowadays, in EU there are 13 bacterial based biocontrol agents (BCA) registered as biopesticides for the control of bacterial and fungal diseases (Bacillus amyloliquefaciens strains: QST 713, AH2, MBI 600, FZB24 and IT 45, *Bacillus amyloliquefaciens subsp. plantarum* strain D747, *Bacillus firmus* I-1582, *Bacillus pumilus* strain QST 2808, *Bacillus subtilis* strain IAB/BS03, Pseudomonas sp. strain DSMZ 13134, Pseudomonas chlororaphis strain MA 342, *Streptomyces* K61 and *Streptomyces lydicus* strain WYEC 108) (Bonaterra et al., 2022a). Bacillus species such as *Bacillus amyloliquefaciens*, *Bacillus subtilis*, and *Bacillus pumilus* isolates could inhibit the growth of Xcc to varying degrees. *B. subtilis, B. pumilus, Bacillus megaterium, Bacillus cereus, Bacillus velezensis, Paenibacillus, and Bacillus thuringiensis* also showed significant antibacterial activity against the Xcc. Strains identified *as Bacillus velezensis* X5-2, *Bacillus megaterium* X6-3, and *Pseudomonas orientalis* X2-1P were effective in vitro and in vivo when applied as a whole-cell suspension form and also as a cell-free supernatant form against Xcc. The greenhouse in vivo tests on winter oilseed rape plants with three selected biocontrol strains lead to a disease reduction of 82.37% and 72.47% in preventive and curative treatments, respectively. Twenty-four isolates of *Paenibacillus spp.*, obtained from New Zealand-grown brassica hosts or soil, were evaluated for in vitro antagonism and biocontrol against six Xcc isolates. Seven *Paenibacillus spp. isolates* with different levels of in vitro suppressive activity against Xcc were screened in pot experiments for their ability to reduce black rot disease on cabbage. Two *Paenibacillus* isolates (P10 and P16) isolates exhibited effective biocontrol activity against Xcc. *B. subtilis R14*, B. megaterium pv. cerealis RAB7, *B. pumilus* C116, and *B. cereus* C210 showed antibiotic activity in vitro against the bacterium *X. campestris pv. campestris*, the causative agent of black rot in crucifers(Luna et al., 2002). In their study metabolic products released by *B. subtilis* R14 produced highest inhibition zone against Xcc in agar diffusion assay. Fifty-four isolates from rhizosphere soil of *Brassica campestris* were screened against Xcc. Two isolates, *Pseudomonas aeruginosa* and *Bacillus thuringiensis* shown higher inhibition against Xcc in the vitro assay. The combined use of them produced the highest inhibition zones against Xcc. In greenhouse study, both isolates were effective in reducing black rot lesions compared to untreated control involving either a foliar spray or the combined seed soak and soil drench. However, the combined strains were significantly more effective when the mode of application was combined seed and soil drench (Mishra and Arora, 2012). Seventeen strains of pathogenic Xcc were tested for sensitivity to 31 bacteriophages isolated from several black rot infected farmer's fields from India. Bhoyar It was found that some lytic phages, especially phage Xcc9SH3, possess superior ability as biocontrol agent. Xcc9SH3 isolated from soil sample from Lucknow was found to lyse all tested 17 strains of Xcc in vitro. (Bhoyar et al., 2017).

5.6 Management of bacterial plant diseases through phyto extracts

Copper compounds such as copper sulphate, Copper Oxy chloride, Bordeaux mixture (Copper sulphate plus Calcium hydroxide), lime sulfur and antibiotics, formulations with combination of antibiotics such as streptomycin (Streptomycin sulphate plus tetracycline chloride) are the only antibacterial choices to control phytopathogenic bacteria that are readily available in a large part of the world. Several researchers tried to identify crude phyto extracts and extract fractions as Biocontrol agents by *in vitro* laboratory experiments and field pot experiments. But so far, no effective crude phyto extracts or phyto components are available in the market to control phytopathogenic bacteria on par with antibiotics and copper compounds. Fontana *et al* showed that methanol and hydro alcoholic extracts of leaves of *Moringa olifera* and hydro alcoholic extract with maltodextrin are very effective against *Xanthomonas campestris pv* *campestris* (Xcc) and reduced biofilm formation (Fontana et al., 2021) .They showed that the MIC of methanolic, hydroalcoholic and hydroalcoholic maltodextrin extracts of leaves of *Moringa olifera* are 0.5mg/mL and 0.1 mg/mL respectively. Methanol extract, hydro alcoholic extract and hydro alcoholic extract with malto dextrin reduced bio film formation by 62%, 77%, and 73% respectively. They also found that treatment with *Moringa oleifera* extracts on Xcc infected cabbage leaves in vivo was clearing and unblocking of xylem by scanning electron microscopy. On other hand Fontana et al., found that Xcc was more susceptible to petal extracts of *Tagetes erecta* and *Chrysanthemum Coronarium*, by disc diffusion method(Fontana et al., 2023). They produced 24.0 mm and 23.50 mm growth in the inhibition zone respectively against Xcc. They also reported that *Acacia fernesiana (11.5mm), Anthocephalus cadamba* (10.5*)*, *Bombax malabaricum* (11.0mm), *Lathyrus odoratus* (10.5mm), *Rosa damascena* (13.5mm) *Thevetia nerifolia* (11.5 mm) were also effective against *Xanthomonas campestris* pv. *Campestris.* Their study showed that Xcc is most sensitive to the petal extracts of *Tagetes erecta* and *Chrysanthemum coronarium*.

6. Impact of chemical pesticides in Indian agriculture system

In response to growing concerns, the Government of India has completely banned the use of Streptomycin and Tetracycline in agriculture, effective from January 1, 2024. This shift highlights the urgent need for alternative microbial biopesticides and antibacterial botanicals to control and manage bacterial diseases in crop plants. Each pesticide possesses unique properties and toxic effects. The indiscriminate use of synthetic pesticides over time has led to various hazards and toxicity. Pesticide residue refers to any specific substance present in food, agricultural commodities, or other products and animal feed resulting from the use of pesticides. This term also includes any derivatives of pesticide, such as conversion products, metabolites, reaction products that are toxic. Pesticide residues can significantly contaminate the environment, including soil, water, air, and food, posing a threat to both plant and animal life. The intergovernmental standards- setting organization for food standards - Codex Alimentarius Commission establishes maximum residue limits (MRLs) for pesticides in food based on acceptable daily intakes (ADIs). Pesticide residues have been found in ground water surface water and potable water samples in India(Behera et al., 2024). Centre for Science and the environment (CSE), New Delhi carried analysis of pesticide residues in soft drinks in 2006 and published their findings.

Table 2: Summary of plant diseases and causative bacterial pathogens and pest control managements.

Plant species	Disease	Symptoms	*Bacterial pathogen*	Pest control managements	Ref.
Rice	Bacterial blight of rice	Yellowish stripes on leaf blades.	*Xanthomonas oryzae pv. Oryzae*	Bordeaux (copper sulfate: lime: water), Streptomycin copper oxychloride	(Zhong et al., 2024a) Sabri S et al 2023
Cotton	Bacterial blight of cotton	Angular leaf spots, Black arm, boll rot.	*Xanthomonas citri pv. malvacearum*	Copper oxychloride 0.25 % + Streptomycin 100 ppm Copper oxychloride 0.25 % + Agrimycin 100 ppm	(Wheeler et al., 2021)
Cabbage, Cauliflower	Block rot of crucifers	Yellow V-shaped lesions appear along the leaf margins, then entire leaf may yellow, wilt, and fall off. Leaf veins in affected areas turn from green to dark brown to black.	*Xanthomonas campestris pv. campestris*	0.1% Streptocycline Copper Sulphate Lime Sulfur Copper sulphate + Streptocycline	(Greer et al., 2023)
Sugar cane	Leaf scald of sugarcane	White to yellow spots on leaves. A diffuse yellow border of varying widths runs parallel to the pencil line streak.	*Xanthomonas albilineans*	Hot water treatment of planting material streptomycin + tetracycline (60 g/ha/500 l water)	(Bini et al., 2023b) Govindaraju et al.,2019
Apricot, Peach Nectarine Plum Almond	Bacterial spot of stone fruits and almond	Small, water-soaked, grayish areas on leaves. Later the spots become angular and purple, black, or brown in color.	*Xanthomonas arboricola pv. pruni,*	Copper hydroxide Mixture of copper hydroxide and mancozeb	(Garita-Cambronero et al., 2018)
Walnut	walnut blight	Reddish-brown spots with a yellow halo, irregular lesions on the leaf blade, Small black	*Xanthomonas arboricola pv. juglandis*	Copper based sprays	(Kim et al., 2021b) Jenkins 2010

		cankers on twigs, black lesions on shoots, cankers on stem.			
soybeans	bacterial pustule disease in soybeans	Necrotic lesions surrounded by chlorotic haloes on leaf surfaces, fruits.	*Xanthomonas axonopodis pv. glycines*	copper talc and copper + sulphur dust. Streptocycline plus copper salts	(Li et al., 2022a) Patidar 2023
Barley	Leaf streak of Barley	Light brown lesions, several centimeters long.	*Xanthomonas translucens pv. translucens*	Cupric acetate (0.5%)	(Sapkota et al., 2020b)
Wheat, Barley	Leaf streak of wheat, barley	Light brown lesions, several centimeters long.	*Xanthomonas transluscens pv. cerealis*	Cupric acetate (0.5%)	(Shah et al., 2019a)
Corn	Bacterial leaf streak of corn	Lesions can be brown, orange, and/or yellow and are often yellow when backlit. Lesions usually have slightly wavy edges.	*Xanthomonas vasicola pv. vas culorum*	Copper combinations	(Ortiz-Castro et al., 2020) Pietrobon, et al,2021
Cassava	Cassava bacterial necrosis	Angular, water-soaked spots that turn brown and may have a chlorotic blackening of the tips of the stems, ring.	*Xanthomonas cassavae*	Sanitary control, cultural practices Crop rotation	(Zarate-Chaves et al., 2021)
Cassava	Bacterial Blight of cassava	brown to dark-brown water-soaked translucent angular spots on the leaf tissue browning at later stages, occasionally surrounded by a chlorotic halo. diseased shoots die, leaving bare leafless stems pointing upwards.	*Xanthomonas phaseoli pv. manihotis*	Sanitary control, cultural practices Crop rotation	(Zarate-Chaves et al., 2021)
Gross, rice	Streak disease	The streaks are initially dark green, but turn translucent, yellowish-orange, and finally brown.	*Xanthomonas oryzae pv. leersiae*	Copper based combinations	(Tall et al., 2022a)

Banana	Enset wilt, Banana bacterial wilt	A yellowish ooze appears on the leaves, leaves wilt and turn yellow.	*Xanthomonas campestris pv. musacearum*	Copper based combinations, Streptomycin	(Nakato et al., 2018)
Radish Turnip	Bacterial leaf spot	small greasy spots are observed that gradually become necrotic, then dry.	*Xanthomonas campestris pv. raphani (Xanthomonas campestris pv armoraciae)*	Copper based combinations	(Fujikawa and Inoue, 2020b)
Bean	Bacterial blight of bean	Water-soaked spots that may expand and turn brown, surrounded by a yellow halo. sunken, tan, lesions with reddish-brown margins on stem and pods.	*Xanthomonas citri pv. fuscans*	copper sulphate, copper hydroxide, and potassium methyl di thio carbamate can be used as control foliage infection effectively	(de Paiva et al., 2020a)
Mango	Bacterial black spot	Angular black spots, chlorotic spots on leaves, necrotic patches on leaves, black irregular or oblong lesions on fruits.	*Xanthomonas citri pv. mangiferae indicae*	Copper combinations, Streptomycin Teracycline combination.	(Liu et al., 2023b) Sossah, et al, 2024
Pomegranate	Bacterial blight of pomegranate	Dark brown and oily, lesions leading to premature defoliation Water-soaked necrotic spots on stem, branches, fruits.	*Xanthomonas citri pv. punicae*	Bordeaux mixture, Copper oxy chloride, Copper combinations Streptomycin, Streptomycin + Tetracycline,	(Radhika et al., 2021b) Ambadkar etal, 2015 DOI: 10.15740/HAS/IJPS/10.1/19-23
Pepper, Tomato	Bacterial leaf spot	Circular water-soaked lesions 3mm surrounded by yellow halo, pale green spots on fruits later become dark brown.	*Xanthomonas campetris pv. vesicatoria*	Spraying copper-based compounds, streptomycin sulphate, Kasugamycin	(Otten and Buttner, 2021) Pontis et al, 2015
Strawberry	Bacterial angular leaf spot	Small, translucent spots turn reddish brown.	*Xanthomonas fragariae*	copper-containing bactericides streptomycin, Kasugamycin	(Turechek et al., 2023b) Kim et al, 2016

Pepper and Tomato	Bacterial spot	Irregular dark brown greasy lesions turn necrotic on leaves, pale green spots on tomatoes, scab like necrotizing lesions on pepper fruits.	*Xanthomonas hortorum gardneri*	Copper oxy chloride, Copper hydroxide, Bordeaux mixture	(Bernal et al., 2021a)
Pepper, Tomato	Bacterial spot disease	dark brown to black with a wet to greasy appearance, fruit lesions.	*Xanthomonas Euvesicatoria* (*X. perforans*)	Spraying copper-based compounds, streptomycin sulphate, Kasugamycin	(Hernandez-Huerta et al., 2021) Potnis etal., 2015
Grapes	Grapevine bacterial canker	Angular reddish-brown spots surrounded by a yellow halo. Leaves become necrotic and die. Stunted shoots. Flowers become black and die. Wilting of fruits.	*Xanthomonas citri pv. viticola*	copper sprays after pruning and budding; disinfection of pruning tools using a 2% active sodium hypochlorite or a 0.1 % quaternary ammonia solution	(Ferreira et al., 2019a)
Citrus	Citrus canker	Raised, tan to brown lesions on leaves, stems, and fruit.	*Xanthomonas citri pv. citri*	Agrimicina containing 15% streptomycin and 1.5% Tetracycline, Streptomycin plus copper sulphate	(Shahbaz et al., 2022)
Sorghum	Bacterial Leaf Blight of sorghum	Yellow or rust color streaks on leaves.	*Enterobacter asburiae*	Recently I detected disease. Control measures not yet established	(Chen et al., 2023)

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They examined 57 soft drinks samples of 11 brands (7 brands of PepsiCo and 4 brands of Coca Cola) for 15 organochlorine pesticides and 13 organophosphorus pesticides. The range of concentration of total pesticides (organochlorines and organophosphorus) was 2.65 ppb to 31.55 ppb in all 57 samples. The average concentration of total pesticides in all 57 samples was 11.85, which is 24 times the BIS limit for total pesticides in soft drinks. Prolonged reliance on chemical-based pesticides has caused numerous adverse effects, such as soil and water contamination, pesticide residues on crop products, the development of insecticide resistance, and the biomagnification of insecticides in living organisms (Mandakini and Manamgoda, 2021). The extensive application of pesticides over the years has released substantial amounts of chemicals into the atmosphere, contributing to global climate change. Numerous undesirable environmental impacts have been reported in various countries, including contamination of soil, surface water, groundwater, and air, as well as pollution-related diseases, excessive mortality, reproductive toxicity, changes in species abundance, and a loss of ecosystem diversity. Additionally, pesticides have led to the destruction of beneficial insects, depletion of natural resources' productive potential, and the development of pesticide resistance in both target and non-target species (Kumar et al., 2021).

7. Limitations and challenges for biopesticides

Regardless of their great capability, biopesticides are yet to become fundamental tools in agriculture for managing pests and pathogens. It is yet difficult to establish biopesticides that are more potent than chemical pesticides and have broad-spectrum activity, long shelf life, and high environmental tolerance. Fundamental issues in biocontrol research have impeded India's efforts to produce high-quality biopesticide products. The short shelf life of biopesticides is the key concern, influencing both the efficiency of biopesticides against target pests and their competitiveness with chemical alternatives (Samada and Tambunan, 2020). The extensive adoption of biopesticides in India faces several complications, including challenges in efficacy, shelf life, production techniques, and performance in the field. Often, biopesticides have a narrow range of target pests or pathogens, and issues with delivery systems, high production costs, and regulatory setbacks further hinder their use. Intense regulatory approvals, which biopesticides must endure just like synthetic pesticides, are tedious and costly. Moreover, varying regulations across countries can hamper the development and distribution of biopesticides, and restrict their market presence(Assadpour et al., 2024). Higher production costs than synthetic pesticides also deter farmers, who may find chemicals more economical. Presently, biopesticides make up only 1-5% of the global pesticide market, highlighting the need for greater awareness and support for their use. Despite these hurdles, biopesticides hold significant potential to support sustainable agriculture. Continued research and innovation, such as nanoencapsulation technology to improve efficacy and stability, as well as streamlined regulatory frameworks, could significantly boost their viability and acceptance within the agricultural sector (Moosavi and Minassian, 2021).

8. Limitations and challenges for chemical pesticides

Chemical pesticides and have broad-spectrum activity, long shelf life, and high environmental tolerance, higher effectivity and performance etc against target pests and pathogens but responsible for several hazards like pesticide residues in food and water, biomagnification or bioaccumulation, phytotoxicity towards crop plants, development of pesticide or antibiotic resistance in microorganisms and subsequent transfer of antibiotic or pesticide resistance to clinical pathogens etc. Phytopathogenic bacterial strains has developed resistance to copper (Cu) based pesticides(Lamichhane et al., 2018) and to antibiotics such as streptomycin (Batuman et al., 2024). However, antibiotics' use in agriculture is less compared to the human and animal healthcare, but their increased use in agriculture has contributed to the creation of new resistant strains of bacterial pathogens(Islam et al., 2024) and spread of antibiotic resistance from phytopathogenic bacteria to human pathogenic bacteria. Spontaneous development of streptomycin resistance was identified in *Clavibacter michiganensis*. Streptomycin resistant strain- *Clavibacter michiganensis* BT-0505R was produced in laboratory from streptomycin sensitive strain *Clavibacter michiganensis* BT-0505 on exposure to streptomycin(Lyu et al., 2019). A detailed advantages and disadvantages of synthetic and biopesticides for the management of plant diseases and protection are summarized in **Table 3**

Table 3: Summary of the advantages and disadvantages of synthetic and Biopesticides for the management of plant diseases and protection

Commercial Aspect and Human Health	Synthetic pesticides		Biopesticides		Ref.
	Potential Advantage	*Limitations*	*Potential Advantage*	*Limitations*	
Effective Control	Often provide rapid and extensive control of a wide range of pests and diseases, leading to increased crop yields.	develop resistance to synthetic pesticides, rendering these chemicals less effective	Generally, more environmentally friendly and biodegradable, reducing soil and water contamination risks.	Biopesticides may exhibit variable effectiveness depending on environmental conditions such as temperature, humidity, and soil type	(Mawcha et al., 2024; Siddiqui et al., 2023)
Cost-Effective	Economies of scale make synthetic options generally cheaper for farmers, especially for large-scale use.	The price of synthetic pesticides can be significant, especially for high-quality products required for effective pest management.	Typically present a lower risk to human health and non-target organisms compared to synthetic options.	The price of biopesticides can be higher than synthetics past control.	(Felsot and Racke, 2006)
Availability	Synthetic pesticides are easily available	It is only sold by authorized vendors.	Biopesticides are quite expensive compared to synthetic pesticides.	It is quite difficult for viability in all the places	_
Resistance Management	Synthetic pesticides act quickly and are highly effective against a broad range of pests.	Prolonged usage has been directed to resistance in several pests, directing the development of new chemical classes and application strategies	Pests develop less resistance to biopesticides than to synthetic pesticides.	Only few may be applicable for resistance management	(Daraban et al., 2023; Fenibo et al., 2022)
Health Risks	Diverse doses and long-term exposure cause health risks. Management of doses can decrease the health risk.	High doses can lead to immediate health effects such as respiratory distress, carcinogenicity, and neurological disorders.	Biopesticides have fewer side effects and do not cause health hazard effects.	Biopesticides can disrupt hormones, which can lead to several health issues but are comparatively less than synthetic pesticides.	(Haroon et al., 2024).
Variable Efficacy	Synthetic pesticides are highly effective against a broad spectrum of pests and diseases, ensuring immediate results	As pests develop resistance, they cause a decrease in efficacy.	Due to fewer side effects and precision, the efficacy is high.	They may have a narrower action spectrum and can be less effective under certain environmental conditions	(Ayilara et al., 2023)

Environmental Impact	When used as directed, synthetic pesticides do not leave harmful residues on food.	Pesticides can be toxic to many organisms, including birds, fish, beneficial insects, and non-target plants	These pesticides are derived from natural sources, such as plants, bacteria, fungi, animals, and minerals. They are generally safer for use.	Biopesticides can target only a particular range of pests.	(Basaid and Furze, 2024).
Commercial potential	Synthetic pesticides have a longer shelf life than most organic pesticides.	Synthetic pesticides can take decades to degrade	Biopesticides are less toxic to non-target organisms than synthetic pesticides.	Biopesticides can negatively affect soil microorganisms by limiting their ability to produce plant growth-promoting traits.	(Kaur et al., 2024)
Agricultural benefit	High Efficacy: Synthetic pesticides are typically more potent and can quickly reduce pest populations, offering immediate results.	Health Risks: There are potential health risks associated with synthetic pesticide use, including acute poisoning and long-term health effects on humans and animals	Biopesticides tend to be less toxic to non-target organisms, including humans, wildlife, and beneficial insects. This reduces the risk associated with pesticide application compared to synthetic options	Efficacy: Biopesticides may not always be as effective or long-lasting as synthetic pesticides, potentially requiring more frequent applications to achieve the desired pest control	(Rani et al., 2021) & (Alewu and Nosiri, 2011)
Impact on crop yield	Synthetic pesticides improve the crop yield by decreasing the pests.	Synthetic pesticides can harm non-target plants, reducing their ability to photosynthesize and produce seeds	Biopesticides can be used in integrated pest management (IPM) programs to reduce the need for synthetic pesticides while maintaining high crop yields.	Biopesticides can be slower to control pests than conventional pesticides	(Ayilara et al., 2023)
Impact on soil	Synthetic pesticides can increase agricultural productivity by reducing losses from weeds, diseases, and insect pests.	Synthetic pesticides can make soil brittle, reduce soil respiration, and harm soil microorganisms.	Biopesticides are generally less toxic to non-target organisms and degrade more quickly in the environment, reducing pollution risks	Biopesticides can negatively impact soil microorganisms by limiting their ability to produce plant growth-promoting traits	(Wei et al., 2024)
Long term use		Long-term exposure is linked to	Biopesticides are generally	Biopesticides can be less	(Aktar et al., 2009)

	serious conditions, including cancer, reproductive disorders, and neurodegenerative diseases	considered to be environmentally friendly and sustainable. They can reduce the use of chemical pesticides, which can pollute soil, water, and air.	effective than chemical pesticides, with efficacy dropping as low as 50% compared to 80% for chemical pesticides	(Wend et al., 2024)

9. Synthetic pesticides and their impact on human health

10. Synthetic pesticides are chemical factors used to prevent or control pests, including insects, rodents, fungi, weeds, and other unwanted organisms. Instead of their advantages in crop and disease management, synthetic pesticides pose high pitfalls to the environment and health. Pesticides have high health risks, which can be divided into chronic and acute toxicities(Gupta et al., 2023). Acute toxicity can arise from severe doses through inhalation, skin contact, or ingestion, and chronic toxicity will occur from perpetuated exposure. The short term acute adverse effects of pesticide exposure on humans are irritation of skin, rashes blisters, burning sensation of eyes, blindness, nausea, dizziness, diarrhea and death (Shah, 2020). The chronic effects of pesticide exposure on humans are cancer, teratogenicity, reproductive harm, immunotoxicity, neurotoxicity and endocrine disruption. The usage of pesticides has been directed to diverse contamination of the surroundings, which is severely affecting natural resources. This will give rise to long-term effects on the ecosystem(Ahmad et al., 2024). WHO and the United Nations Environment Programme (UNEP) report stated that three million people are being affected, and 2,00,000 deaths occurred due to severe exposure to pesticides in developing countries. Pesticides will increase the production of ROS (reactive oxygen species), which causes a reduction in antioxidant levels and their properties. Due to disparities, proteins, and lipids affect cellular signaling pathways. Chronic health effects are caused by ROS and oxidative stress. Pesticides cause major effects in the ecosystem, which causes adverse effects on human health, from acute intoxication to chronic infection that causes various types of cancer (brain cancer, breast cancer, prostate cancer, and colon cancer), Alzheimer's disease, Parkinson's disease, infertility, leukemia, and diabetes(Mishra et al., 2020). Nonetheless, pesticide use must be harmonized with environmental and health considerations, such as integrated pest management, should be developed to ensure sustainable and effective pest control strategies. Synthetic pesticides have directly or indirectly impact on human health, the example is illustrated in **Figure 2.**

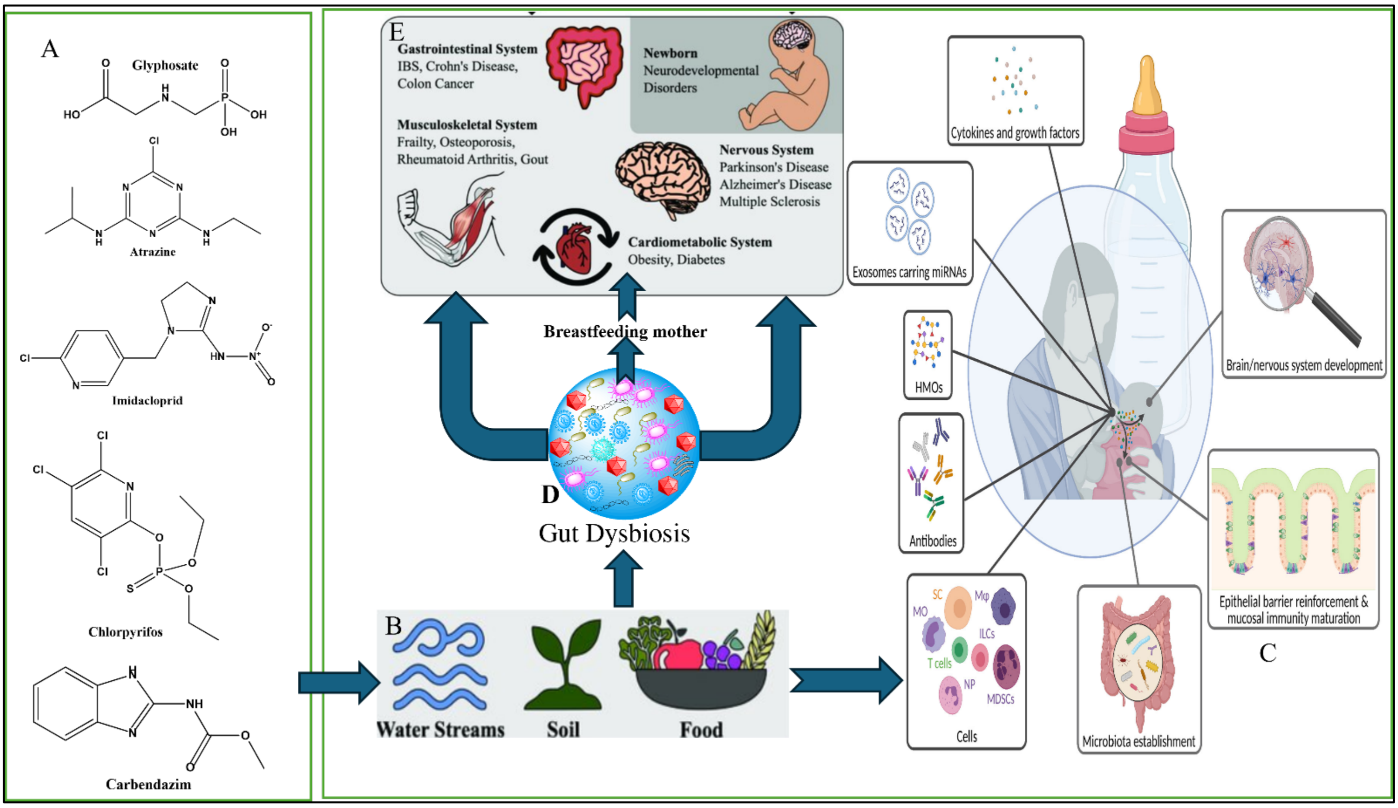

Figure 2: (A) Structural representations of commonly used pesticides. Glyphosate is a widely utilized herbicide that inhibits the shikimate pathway in bacteria, which can alter the composition of gut microbiota. Atrazine is another herbicide known for its impact on gut microbiota and endocrine functions. Imidacloprid, a neonicotinoid insecticide, disrupts gut bacteria and immune responses. Chlorpyrifos, an organophosphate insecticide, is associated with gut microbiome disruptions and neurotoxicity. Carbendazim is a fungicide that negatively affects intestinal microbial diversity. (B) These synthetic pesticides come into direct contact with water streams, soil, and food, leading to environmental pollution that can adversely impact human health. (C) Special attention is given to breast-feeding mothers and their infants, as these pesticides can influence health during this critical development stage. (D) Pesticides are implicated in gut dysbiosis, which is linked to several health issues. (E) The illustration depicts the potential effects of pesticide exposure, including disruptions in the cardiometabolic system, neurodevelopmental disorders, gastrointestinal disorders, and an increased risk of colon cancer.

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12. Future direction and conclusion

Extensive research on plant-derived biopesticides has to be focused on minimizing the health impacts, reducing the toxic effects on the ecosystem, and maintaining sustainability. More research must be investigated on improving the stability of biopesticide, and high potency to make them better options. Various techniques must be developed for biopesticide absorption and persistence. Furthermore, investigating the effect of biopesticides could reduce their toxic effects and reduce environmental impacts. Precision agriculture is also a hot target pesticide application, potentially decreasing the toxic effects on humans and the ecosystem. Additionally, research on the acute and chronic toxic effects, such as carcinogenicity and neurotoxicity, is to be performed on safer usage guidelines, particularly for synthetic pesticides (Cappa et al., 2022). Expanding the screening of diverse plants, especially tropical or medicinal species, may give new bioactive compounds for sustainable pest control. Extensive research should be focused on several limitations of biopesticides, which can be overcome. To ensure the long-term effectiveness of both kinds of pesticides, research into resistance mechanisms will also aid in the creation of strategies to combat resistance. Instead of using frameworks that are focused on synthetic compounds, it would be safer and more efficient to develop safety and efficacy testing standards specifically designed for biopesticides. By bridging the gap between synthetic and natural components, consistent worldwide regulatory rules that support biopesticide research and application can enable sustainable pest management on a global scale. These future directions aim to create more effective and safe pest control solutions that balance plant protection needs with human health and environmental safety.

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Data Availability

NA

Conflict of interest

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Abbreviation

GDP	:	Gross domestic product
PD	:	Parkinson's disease
Xee	:	*Xanthomonas euvesicatoria pv. euvesicatoria*
Xep	:	*Xanthomonad euvesicatoria pv. perforans*
Xhg	:	*Xanthomonas hortorum pv. gardneri*
Xcc	:	*Xanthomonas campestris pv. campestri*s
Pcc	:	*Pectobacterium carotovorum* subsp. carotovorum
Psm	:	*Pseudomonas syringae pv. maculicola*
Bt	:	*Bacillus thuringiensis*

EPA	:	Environmental protection agency
U. S	:	United states
NACs	:	Nano-agrochemicals
HPLC	:	High performance liquid chromatography
LCMS	:	Liquid chromatography- mass spectrometry
PGPR	:	Plant growth-promoting rhizobacteria (PGPR)
EU	:	European Union
ADIs	:	acceptable daily intakes
WHO	:	World health organization
CSE	:	Centre for Science and environment
ROS	:	Reactive Oxygen species
UNEP	:	United nations environment programme

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