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Assessment of Pesticide Degradation Efficacy of Probiotics Isolated From Foods

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ABSTRACT

The extensive use of pesticides in agriculture has resulted in the presence of pesticide residues in food and feed, which poses a serious risk to human health. Many physical and chemical methods can be used to eradicate pesticides, but most of them are either costly or vulnerable to secondary contamination. Thus, the use of microorganisms, such as probiotics, to eliminate pesticides has emerged as a promising alternative. Some probiotic bacteria, mainly *Lactobacilli,* have received a lot of attention due to their toxicity reduction ability of several contaminants. For example, *Lactobacilli* can reduce the accumulation and toxicity of selective heavy metals and pesticides in animal tissues by inhibiting the intestinal absorption of contaminants and improving the intestinal barrier. Probiotics reduce the risk of antibiotic-associated diarrhea, perhaps by competing and producing antagonistic compounds against pathogenic bacteria. Mechanisms of these beneficial bacterial strains in the remediation process have been explored and especially their interaction with the host gut microbiota. In this review, we summarize research progress on the remediation mechanisms of some probiotics as well as the combined effects of probiotics and gut mirobiota on the remediation of foodborne contaminants *in vivo*.

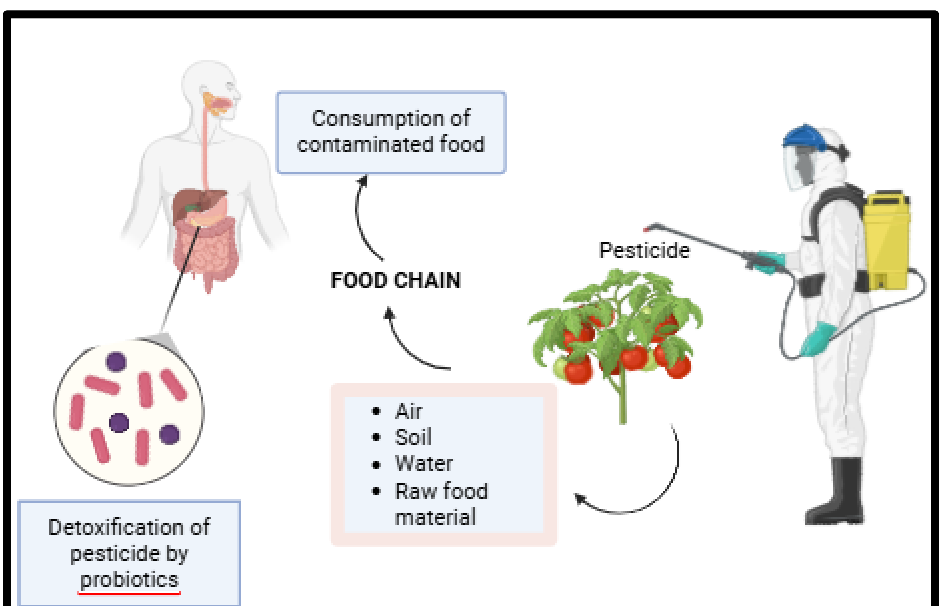

Fig 1: Graphical Abstract

INTRODUCTION

Food and Agriculture Organization (FAO) defined a pesticide as any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood, or wood products, or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids, or other pests in or on their bodies (World Health Organization, 2015; Pathak et al.,2022).

The term includes substances intended for use as a plant growth regulator, defoliant, desiccant, or agent for thinning fruit or preventing the premature fall of fruit, or which conforms to the definition of a plant regulator, defoliant, desiccant, or agent for thinning fruit or preventing the premature fall of fruit in section 25(b) of the Federal Insecticide, Fungicide, and Rodenticide Act, an antimicrobial, an animal repellent, an herbicide, a fungicide, a rodenticide, a nematicide, a piscicide, or a miticide. They include herbicides, insecticides, nematicides, fungicides, and many others. The most commonly used pesticide is herbicides, which account for approximately 50% of all pesticide use in the world. Most pesticides are used as agricultural products which in general protect plants from weeds, fungi, or insects. Pesticide can be defined as a chemical or biological agent that deters, incapacitates, kills, or otherwise discourages pests (World Health Organization, 2015; Pathak et al.,2022).

Outside of their main trunk use in agriculture, pesticides have several other applications. Pesticides are used to control organisms that are thought to be harmful, or pernicious to their environment. For example, they are used to kill mosquitoes that can transmit potentially deadly diseases such as West Nile virus, yellow fever, and malaria. It can kill bees, wasps, or ants that can cause allergic reactions. Insecticides can protect animals from illnesses that can be caused by parasites such as fleas. It can prevent sickness in people by killing moldy food or diseased produce. Herbicides can be used to clear roadside weeds, trees, and brush. Herbicides are commonly applied in ponds, lakes, and rights of way to control algae and plants such as water grasses that can interfere with activities like swimming, fishing, and even the aesthetics of the water (Rajak *et al*., 2023).

Uncontrolled pests such as termites and mold can damage structures such as houses. Pesticides are used in grocery stores and food storage facilities to manage rodents and insects that infest food. Pesticides are used in homes to control pests such as termites that can cause structural damage and insecticides are used to kill insects that infest human homes. Pesticides are used in public health to prevent the spread of diseases. During an outbreak of yellow fever in Cuba in 2005, it also used aerially to kill mosquitoes and limit the spread of the disease. Pesticides are used in gardens to kill unwanted insects or weeds (Rehwagen *et al*., 2006; Sadasivaiah *et al*., 2007; Deguine *et al*., 2021).

Pesticides are used on lawns and golf courses, partly for cosmetic reasons. Many are turning to integrated pest management, using various methods to control pests, with success in countries such as Indonesia, China, Bangladesh, U.S., Australia, and Mexico. IPM recognizes that pest populations will inevitably adjust to a single control method and seeks to maintain a balance. Each usage of a pesticide brings a measure of risk, but with proper usage, these risks may be reduced to a level acceptable by governing pesticide regulatory agencies such as the EPA (United States Environmental Protection Agency) in the U. S. or the Pest Management Regulatory Agency (PMRA) in Canada (Rehwagen *et al*., 2006; Sadasivaiah *et al*., 2007; Deguine *et al*., 2021).

Di-chloro-diphenyl-trichloro-ethane (DDT), sprayed on the walls of houses, is an organochlorine that has been used to fight malaria vectors (mosquitos) since the 1940s, a World Health Organization solution. DDT and other organochlorine pesticides were banned in most countries globally because of the dangers of their persistence in the environment and human toxicity. (Rehwagen *et al*., 2006; Sadasivaiah *et al*., 2007; Deguine *et al*., 2021).

1. Classification of pesticides

Pesticides can be classified by target organism (herbicides, insecticides, fungicides, rodenticides, and pediculicides), Biopesticides as defined by the EPA include microbial pesticides, biochemical pesticides, and plant incorporated protectants. Pesticides can be classified into structural classes based on their mode of action. Many structural classes have been developed for each of the target organisms (Table 1). A structural class is usually associated with a single mode of action while a mode of action may encompass more than one structural class. Pesticides may be systemic or non-systemic. A systemic pesticide translocates inside the plant. While non-systemic pesticides remain on the surface and act through direct contact with the target organism. Systemicity is a prerequisite if the pesticide is to be used as a seed-treatment (Feng *et al*., 2018; Mohammandi *et al*., 2021; Karegoudru *et al*., 2022; López-Moreno *et al*., 2022; Ampatzoglou *et al*., 2022; Ahamad *et al*., 2023). Pesticides are either persistent (non-biodegradable) or non-persistent (biodegradable). It has to be persistent enough to kill or control its target, but not so persistent as to accumulate in the environment or in the food chain (Fig 2). It must degrade fast enough to meet these criteria in order to be approved by the authorities. Persistent pesticides such as DDT have long since been banned, with the exception of spraying in houses to combat malaria vectors (Datta *et al*., 2001; Mkindi *et al*., 2017; Ayilara *et al*., 2023; Garud *et al*., 2024).

Table 1: Pesticides and its application against target pathogens.

Category	Example of pesticides	Target	Example of Traget organism	Reference
Insecticides	Malathion, DDT	Insects	Mosquitoes, Aphids, Caterpillars	Chandraleka *et al*., 2024
Herbicides	Glyphosate	Weeds/unwanted plants	Crabgrass, Dandelions, Pigweed	Goss *et al*., 2003
Fungicides	Mancozeb, Chlorothalonil	Fungi	Powdery mildew, Rust fungi, Late blight	Kinney *et al*., 2005
Rodenticides	Warfarin, Bromadiolone	Rodents	Rats, Mice	Redfern *et al*., 1980
Nematicides	Aldicarb, Fenamiphos	Nematodes	Root-knot nematodes, Cyst nematodes	Krause *et al*., 1986

Molluscicides	Metaldehyde, Ferric phosphate	Snails/slugs	Garden slugs, Apple snails	Buhl *et al.*, 2013
Bactericides	Copper sulfate, Streptomycin	Bacteria	Fire blight (Erwinia amylovora), Bacterial spot	Bowen *et al.*,1971

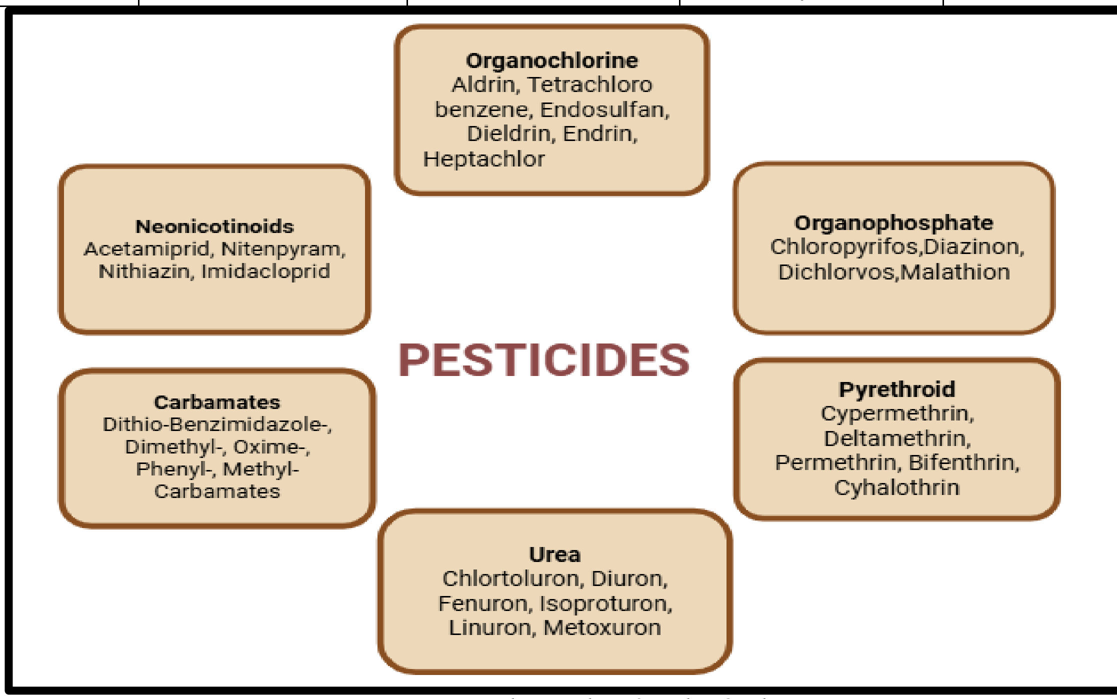

Fig 2 : Pesticides residues found in food

2. Effects of pesticides

Most health issues arise from the direct use of pesticides, whether in occupational or non-occupational settings. Health risks from pesticide residues in fruits and vegetables are considered less. Occupational use of pesticides can affect health, either by mimicking hormones and causing reproductive problems, and also cancer. A 2007 systematic review noted that "most studies on non-Hodgkin lymphoma and leukemia showed positive associations with pesticide exposure" and so recommended that the cosmetic use of pesticides should be decreased (Bassil *et al.*, 2007). There is substantial evidence of associations between organophosphate insecticide exposures and neurobehavioral alterations. There is limited evidence for other negative outcomes from pesticide exposure, including neurological, birth defects, and fetal death (Ali *et al.*, 2021; Beyuo *et al.*, 2024). A review in 2014 found associations between autism and exposure to certain pesticides, but noted the evidence was not sufficient to conclude that the relationship was causal (Kalkbrenner *et al.*, 2014). 99% of pesticide-related deaths occur in the developing world, where in many instances pesticides are used in excess. According to the American Cancer Society, there is no evidence that pesticide residues in food increase the risk of people getting cancer (Roman *et al.*, 2024)

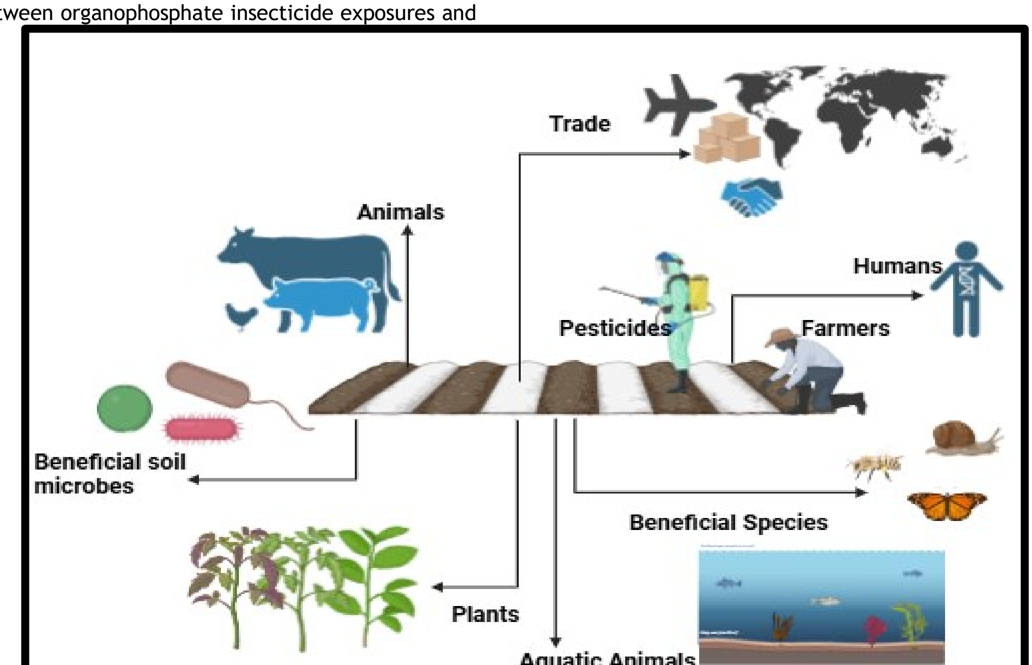

Fig 3: Impact of pesticide on all living ecosystem.

3. Environmental effects

The use of pesticides raises a number of environmental concerns. Over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, including non-target species, air, water and soil(Fig 3). Pesticide drift occurs when pesticides suspended in the air as particles are carried by wind to other areas, potentially contaminating them. Pesticides often contaminate water sources, and some pesticides are persistent organic pollutants (now banned), which contribute to soil and flower (pollen, nectar) contamination. Furthermore, it can harm neighbouring agricultural areas, as pests themselves drift to and harm nearby crops, which have no pesticides applied to them (Lushchak *et al.*, 2018).

In addition, it also use reduces invertebrate biodiversity in streams, contributes to pollinator decline, destroys habitat (especially for birds), and endangered species. Other problems can include murder of pollinators or destruction of habitat for other organisms. Alternatively a greater dose of pesticide can be used to counteract the resistance, although this will further worsen the ambient pollution. The Stockholm Convention on Persistent Organic Pollutants banned all persistent pesticides, in particular DDT and other organochlorine pesticides, which were stable and lipophilic, and thus able to bio-accumulate in the body and the food chain. and which spread throughout the planet. Persistent pesticides are not used in agriculture, and will not be approved by the authorities (Mostafalou *et al.*, 2017).

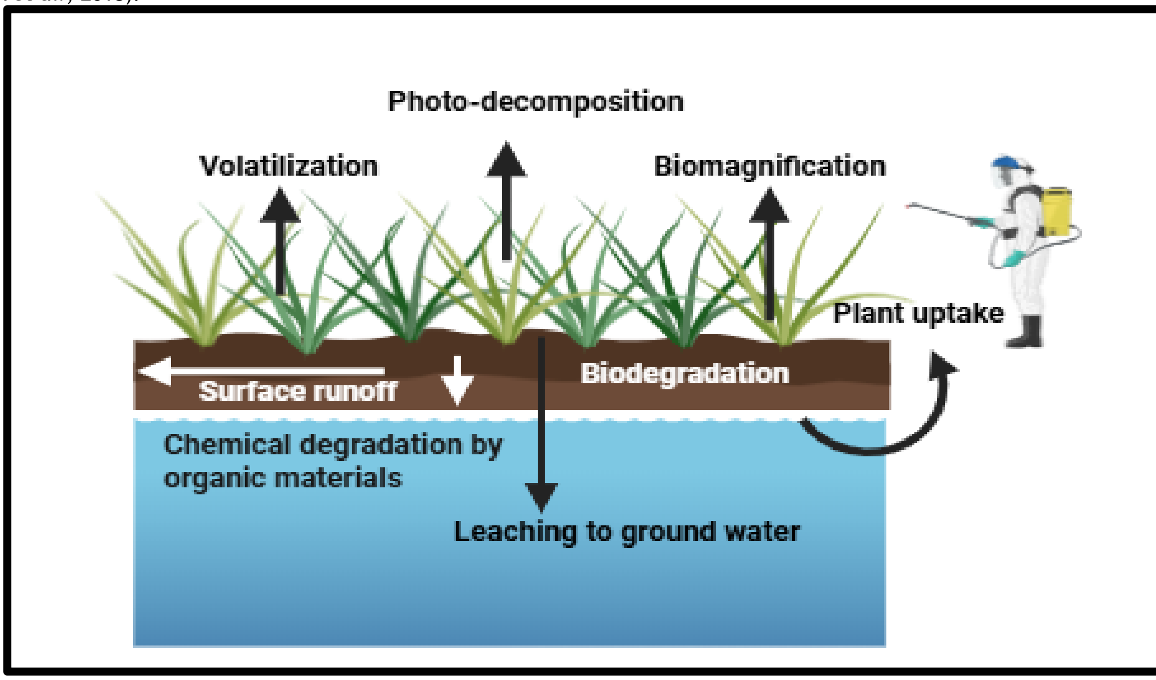

Fig 4 : Impact of pesticide residue on soil ecosystem.

Degradation of pesticides is due to both innate chemical properties of the compounds and environmental processes or conditions(Fig 4). For example, the presence of halogens within a chemical structure often slows down degradation in an aerobic environment. Adsorption to soil may retard pesticide movement, but also reduce bio-availability to microbial degraders. Pesticide contamination in the environment can be monitored through bio indicators such as bee pollinators (Pathak *et al.,* 2022)

4. Benefits of probiotics

Probiotics are live microorganisms that provide health benefits when consumed, generally by improving or replacing the microorganisms of the gut flora. Probiotics are generally considered to be safe to consume, though some bacteria-host interactions and unwanted side effects have been noted. There is some evidence that they are effective for some conditions, such as irritable bowel syndrome, antibiotic-associated diarrhea, and travelers' diarrhea, but the quality of evidence is not strong and for other conditions there is no evidence to support use (Fijan *et al.*, 2014). Many claimed health benefits, such as treating eczema, or curing vaginal infections are not supported by the evidence. The first discovered probiotic was a strain of *bacillu*s in Bulgarian yoghurt in 1905 by Bulgarian physician and microbiologist Stamen Grigorov. Élie Metchnikoff is the modern-day father of probiotics and put forward the Nobel Prize in 1907 that consumption of yoghurt helped Bulgarian peasants live longer. The market for probiotics is growing, leading to stricter requirements for scientific substantiation of putative benefits conferred by microorganisms that are claimed to be probiotic. Although some evidence supports claimed benefits for probiotics, such as reducing gastrointestinal discomfort, improving immune health, relieving constipation, or avoiding the common cold, such claims are strain-specific and cannot be extrapolated to other strains (Das *et al.*, 2022).

5. Bio-remidiation of pesticides

The extensive use of pesticides in agriculture has affected human health and environment. Pesticide residues are commonly found in food, water, and soil and their long-term exposure has been linked with health problems such as endocrine disruption, neurotoxicity, and cancer. Probiotics, known for their beneficial effects on gut health, can sequester, degrade, and neutralize various pesticide compounds acting as effective detoxifying agents. Different types of microbial spices are having bio-remidiation efficacy among microbial species. A group of bacteria can bio-remidiate various types of pesticides, heavy metals or toxic materials on the Eco system. Among bacteria *Pseudomonas, Bacillus, Acetobacter, Asinetobacter*, lactic acid bacteria and few fungal species can degrade these toxic substances at different levels. *Bacillus* species demonstrated that they are not only pesticide tolerant but they can also degrade different types of chemical pesticides such as malathion, fipronil, profenophos, cyhalotrin, λ-cyhalothrin under various climatic conditions (Geed *et al.*, 2022; Singh *et al.*, 2012; Ishag *et al.*, 2016; Bhatt *et al.*, 2021; Zhou *et al.*, 2021; Pakar *et al.*, 2024; Silambarasan *et al.*, 2022; Shahid *et al.*, 2023; Sharma *et al.*, 2024; Umar *et al.*, 2024; Huang *et al.*, 2024; Wu *et al.*, 2025).

These species have proven their pesticide degrading ability under *in-vitro* and *in-vivo* condition. Most of these organisms have been used as a bio-fertilizer, bio-control agent or bio-inoculant. Resent studies have reported that lactobacillus species such as *Lactobacillus plantarum* (various strains) has shown to degrade dimethoate, malathion, and other organophosphate pesticides under various ecological conditions (Yuan *et al.*, 2022). Similarly *Lactobacillus brevis* WCP902, *Lactobacillus sakei* WCP904 and *Lactobacillus plantarum* WCP931 has identified for its ability to degrade chlorpyrifos and (Trinder *et al.*, 2016; Haque *et al.*, 2018; Haque *et al.*, 2020; Lee *et al.*, 2021; Kiruthika *et al.*, 2025).

7. Mechanism of bio-remidiation

Common probiotic strains include bacteria from the genera *Lactobacillus, Bifidobacterium, Bacillus,* and yeast from the genus *Saccharomyces.* While they have long been used for digestive health and immune boosting, recent studies have shown that they can help to detoxify poisons, including pesticides. Degradation is one of the major mechanisms by which probiotics are able to detoxify pesticides. Some strains possess enzymes capable of breaking down the pesticide molecules into less or non-toxic molecules. For instance, *L. plantarum and B. subtilis* were shown to produce organophosphorus hydrolases that can break down the highly toxic organophosphate pesticides such as chlorpyrifos and diazinon (Kumar *et al.*, 2019; Shahid *et al.*, 2021; Lu *et al.*, 2023; Sales *et al.*, 2024).

In addition to enzymatic breakdown, probiotics can bind pesticide molecules to their cell walls, a process known as adsorption. This reduces the uptake of pesticides in the human gastrointestinal tract (Fig 5). The cell wall components of probiotics, which are peptidoglycan, teichoic acids, and exopolysaccharides, can bind with the pesticides and reduce their bio-availability, making them easier for the body to excrete. Probiotics can also help with detoxification indirectly by boosting the host's antioxidant defenses. Many pesticides cause their toxicity by creating free radicals and causing oxidative stress (Kumar *et al.*, 2019; Shahid *et al.*, 2021; Lu *et al.*, 2023; Sales *et al.*, 2024).

Probiotics can reduce this by increasing the activity of antioxidant enzymes such as superoxide dismutase, catalase, and glutathione peroxidase to protect the cells from oxidative damage (Markowiak *et al.*, 2017; Średnicka *et al.*, 2021; Baralic *et al.*, 2023; Petrariu *et al.*, 2024). *Lactobacillus species* also have a role in the bio-degradation of pesticides, especially organophosphate pesticides with the assistance of an enzyme phosphatase. *L. plantarum* strain was able to degrade pesticides such as dimethoate and malathion (Pinto *et al.*, 2019; Lee *et al.*, 2021). *Bacillus* species commonly used for the bio-degradation of pesticides and produce extracellular enzymes which can degrade wide range of organic compounds including pesticides. *Bacillus* species like *Bacillus sp.* S4 degrading malathion, which is an organophosphate pesticide (Kumar *et al.*, 2019; Shahid *et al.*, 2021; Lu *et al.*, 2023; Sales *et al.*, 2024).

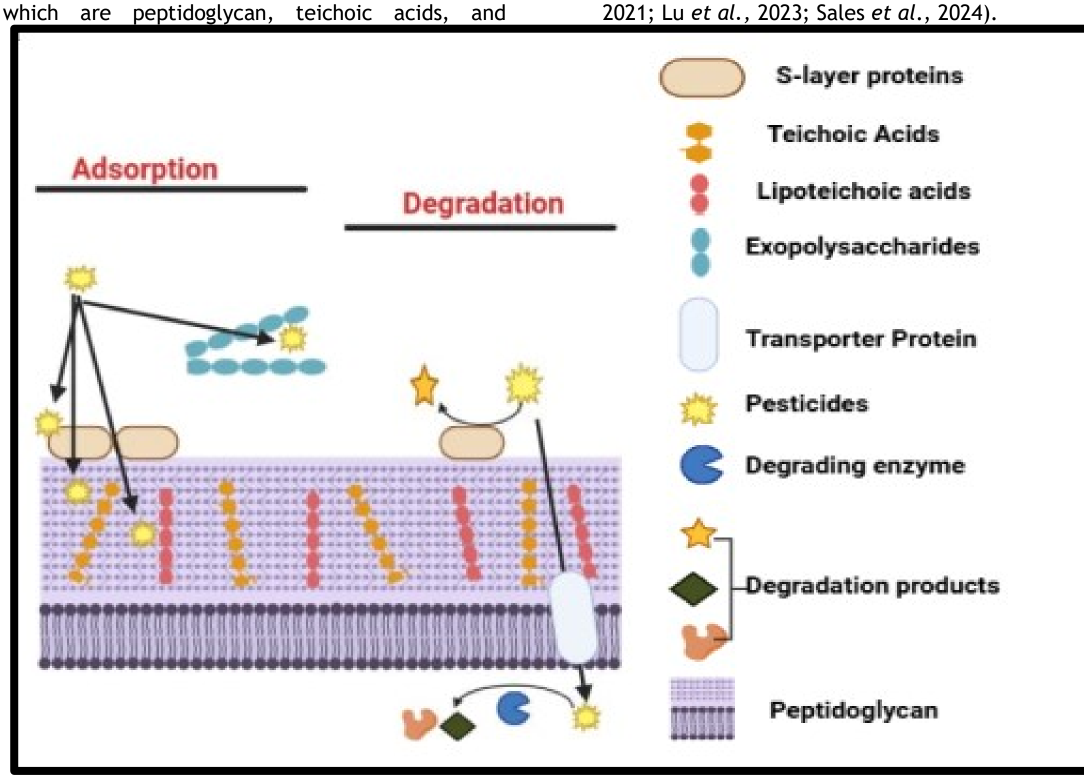

Fig 5: Mechanism of pesticide degradation by probiotic microorganism

CONCLUSION

In recent days, the application and use of pesticide has been increased in many folds to maintain the food sustainability. Most of the pesticide are having negative impact on ecosystem. Therefore, employing microorganisms like probiotics for bio-remediation could be a potential solution to this problem. Pesticides can be detoxified by probiotics through the release of hydrolytic enzymes. While the majority of studies focus on organophosphate pesticides, there aren't many that evaluate probiotics ability to break down such substances. Like other microbes, group of lactic acid bacterial species can also be used as bio-remediate pesticides present in food and the soil. This will be the alternative to chemical methods.

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