Microbial Degradation of Pesticides in Agricultural Environments: A Comprehensive review of Mechanisms, Factors and Biodiversity

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Abstract: -Pesticides are used frequently in modern times to prevent and manage crop pests and diseases, but their residual effects have seriously harmed both the environment and the health of humans. Within the fields of all over the world applied restoration of the environment science and technology, the study of microbial breakdown of pesticides in soil ecosystems is a significant research area. Agricultural methods depend on the use of chemicals, including pesticides and herbicides, to control pests and weeds. However, these chemicals pose risks to the environment, human, and animal well-being. Microbes have shown promise in degrading these agricultural environmental hazards, mitigating their negative impact. The organisms that exist in the natural world, the research on bacteria that break down pesticides and herbicides, and the approach for the application of these bacteria has been summarized in the paper.

This literature review aims to identify the microbes responsible for degrading these chemicals and assess their effectiveness in doing so. The goal of this review is to determine the bacteria responsible for the deterioration of agricultural environmental hazard chemicals, evaluate their efficacy in degrading these compounds, explore the factors influencing microbial degradation efficiency, and identify research gaps in the field. Inclusion criteria encompass studies published in English between 2010 and 2023 that focus on the degradation of agricultural environmental hazard chemicals by microbes, specifically microbial consortia, under controlled conditions. A systematic literature review will be conducted using databases like ScienceDirect, Web of Science, and PubMed. Data extracted from selected studies will include information on pesticide types, microorganisms involved in degradation, mechanisms of microbial degradation, factors affecting microbial degradation, current trends in microbial degradation of pesticides, biodiversity of pesticide-degrading microbes, plasmid-borne pesticide resistance in bacterial communities, and strategies for pesticide degradation by microbial consortia. This research tries to present a comprehensive knowledge of microbial degradation mechanisms, highlight the potential of microbial consortia in pesticide degradation, and contribute to sustainable and eco-friendly approaches for addressing pesticide residues in agricultural environments. This study focused on the variables that affect the microbial breakdown of pesticides and the technique by which microorganisms decompose under natural conditions. In addition, the current trends of research on the microbial degradation of pesticides as well as a few visible challenges that continue to need attention were described.

Keywords: Microbes, Microbial degradation, Biodiversity, Pesticide degradation, Microbial consortia.

Received: March 16, 2024. Revised: Agust 11, 2024. Accepted: September 15, 2024. Published: October 14, 2024.

1. Introduction

India supplies 250 million tons of grains each year on average, but pests and other conditions cause it to lose 11–15% of the total, or nearly 27.5–37.5 million tons annually [1]. Chemicals like pesticide are often utilized to manage domestic and agricultural insects in order to prevent such damages [2]. The use of pesticides has drastically reduced food loss, yet crops, water, air, and soil all contain huge quantities of these substances. Therefore, there is significant danger to the ecosystem from the widespread consumption of pesticides [3, 4]. They directly harm human health and the ecosystem by poisoning not only the land and crops but also the ground water and the marine environment [5, 6, 7, 8, 9, and 10].

Pesticides are used to a crucial role in modern agricultural practices by protecting crops from pests and diseases, ensuring global food security, and increasing agricultural productivity [11]. However, the indiscriminate and extensive use of concerns about pesticides' detrimental impact on the environment, human health, and biodiversity. These chemicals can persist in agricultural environments, leading to water and soil contamination, and posing a threat to ecosystems and ecological balance. Recently, there has been an expanding recognition of the need for sustainable agricultural practices that minimize the use of harmful chemicals and promote environmentally friendly alternatives.

The breakdown of pesticides by bacteria, fungi, and other microorganisms that consume pesticides are known as microbial degradation. The vast majority of pesticide microbial breakdown takes place in soil. Because they directly affect the development of bacteria and activity, soil characteristics including temperature, moisture, air circulation, pH, and the quantity of organic material have an effect on how quickly microorganisms destroy resources.

Microbial degradation of pesticides has emerged as a promising solution to mitigate the environmental impact of these chemicals. Microorganisms, including bacteria, fungi, and archaea, possess unique enzymatic capabilities that give them a chance to collapse and detoxify a variety of pesticide compounds [12]. This process, known as microbial degradation, involves the enzymatic transformation of pesticides into less toxic or non-toxic substances, it may also be used by humans as a source of carbon and energy for microbial communities. Understanding the mechanisms and factors influencing microbial degradation of pesticides is crucial for the growth of efficient bioremediation techniques, as well as the optimization of microbial degradation processes.

We can begin by considering the following two factors in order to sort out the issue between agricultural goods with a high yield or consistent production and damage to the environment. Identifying and creating pesticides with low harmful effects, high effectiveness, and low pesticide residues is essential but there should also be a primary emphasis on methods for breaking down pesticide residues. The 1940s seen the beginning of studies on the microbial degradation of pesticide residues, and as awareness of environmental issues has grown, so has the amount of understanding regarding the breakdown mechanism and process of organic pollutants into the atmosphere. [13]. As an outcome, scientists have studied bacteria in great depth and have a solid understanding on how organic pesticides decompose down. A number of microorganisms that have the ability to dissolve down and degrade pesticides have been recognized among them [14, 15, and 16]. Further, an in-depth overview of the mostly biodegradable processes and mechanisms of pesticides has been offered [15, 17, 18, and 19]. According to current research, biodegradable pesticides are mainly concentrated in soil-based microorganisms, including fungal and bacterial organisms and actinomycetes [20], with the primary function played by fungi and bacteria. Further investigation can be done since the bacteria could easily produce variant strains, which also possessed a variety of metabolic capacities to adapt to their surroundings [21, 22, 23, 24, and 25].

The study of microbial decomposition of pesticides is interdisciplinary, encompassing microbiology, biochemistry, environmental science, and agronomy [26]. Numerous research has been carried out to look at the microbial degradation of pesticides, shedding light on the enzymatic pathways involved, the factors influencing degradation rates, and the function of the microbiological biodiversity in shaping pesticide degradation processes.

However, the knowledge in this field is scattered across various scientific disciplines, making it challenging to have a comprehensive understanding of the subject matter.

This comprehensive review aims to consolidate and synthesize the existing knowledge on microbial degradation of pesticides in agricultural environments. It provides an in-depth analysis of the mechanisms, factors, and biodiversity involved in the degradation process. By examining the scientific advancements and practical implications of microbial degradation, this review seeks to bridge the gap between research and practical implementation, promoting the adoption of sustainable pesticide management practices in agriculture. Additionally, the review identifies current research gaps and highlights areas for future investigation, encouraging further exploration and advancements in the field of microbial degradation of pesticides.

Through a systematic analysis of relevant scientific literature, this review aims to advance knowledge of microbial degradation mechanisms, factors influencing degradation efficiency, and the role of microbial biodiversity in pesticide degradation. The findings of this review will not only provide valuable insights for researchers, policymakers, and agricultural practitioners but also support the development of effective bioremediation techniques, as well as the promotion of environmentally friendly approaches to pesticide management in agricultural environments.

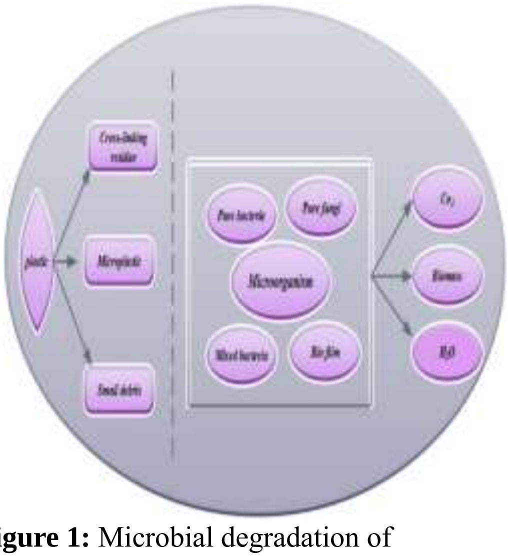

Figure 1: Microbial degradation of Environment

1.1. Need for the survey

- Understand and minimize the environmental impact of pesticides by exploring microbial degradation mechanisms.
- Promote sustainable agriculture through the use of microbial degradation to reduce the reliance on harmful chemicals.
- Consolidate and update existing knowledge in the field of microbial degradation of pesticides.
- Develop effective bioremediation strategies for pesticide-contaminated environments.
- Highlight the importance of microbial biodiversity conservation in pesticide management.
- Provide practical insights for researchers, policymakers, and agricultural practitioners in implementing sustainable pesticide management practices.
- Identify research gaps and guide future studies to advance the field of microbial degradation of pesticides.

1.2. Motivation for the Survey

This literature review is driven by the urgency to tackle environmental concerns associated with pesticide use and find sustainable solutions for their remediation. It aims to consolidate and synthesize existing knowledge on microbial degradation of pesticides, providing a comprehensive understanding of the mechanisms, factors, and biodiversity involved. By exploring microbial degradation, this review contributes to the development of environmentally friendly strategies for pesticide management, fostering sustainable agriculture. It also addresses the effect of pesticides on biodiversity and examines practical applications of microbial bioremediation techniques. Furthermore, the review aims to inform policy decisions and guide future research, encouraging the adoption of evidence-based practices and further advancements in the field**.**

1.3. Challenges Of the Review

Data Availability: One of the challenges in conducting this comprehensive review is the availability of diverse and reliable data. Pesticide degradation studies may vary in terms of methodologies, sample sources, and target compounds, making it challenging to compare and synthesize the findings. Additionally, access to unpublished or nonpeer-reviewed research and data from different geographical regions can be limited, potentially affecting the completeness of the review.

The complexity of Microbial Systems: Microbial communities are highly diverse and complex, consisting of various species with different metabolic capabilities. Understanding the specific contributions of individual microbial species or groups to pesticide degradation can be challenging. Microbial interactions and the influence of community dynamics on degradation processes are complex and not yet fully elucidated, further adding to the challenge.

Variability in Environmental Factors: Environmental elements are involved. a critical part ofthe microbial degradation of pesticides. However, these factors, such as temperature, pH, moisture, and nutrient availability, can vary significantly across different agricultural environments. Incorporating this variability into the review and drawing general conclusions can be challenging, as the optimal conditions for microbial degradation may differ based on the specific pesticide and environmental context.

Lack of Long-Term Studies: Pesticide degradation studies often focus on short-term experiments, providing limited insights into the long-term effects and sustainability of microbial degradation processes. Understanding the long-term efficacy, stability, and potential for microbial adaptation and evolution in response to pesticide exposure requires comprehensive and long-term studies, which may be limited in availability.

Knowledge Gaps and Emerging Research: The field of microbial degradation of pesticides is rapidly evolving, with new research emerging continuously. This review may face the challenge of capturing the latest advancements and addressing recent knowledge gaps. The literature review process needs to be thorough and up-to-date to ensure the inclusion of the most relevant and recent studies.

Implementation Challenges: While microbial degradation shows promise as a sustainable approach to pesticide remediation, the practical implementation of microbial bioremediation strategies in agricultural systems can face challenges. Factors such as scalability, cost-effectiveness, regulatory considerations, and acceptance by farmers and stakeholders need to be addressed for successful implementation, but these aspects may not be extensively covered in the existing literature.

Bias and Interpretation: As with any comprehensive review, there is a potential for bias in the selection and interpretation of studies. The review process should employ rigorous methodologies to minimize bias, such as systematic search strategies, inclusion criteria, and critical evaluation of study quality and relevance.

Despite these challenges, this comprehensive review aims to provide an insightful synthesis of existing knowledge, highlighting the mechanisms, factors, and biodiversity involved in microbial degradation of pesticides in agricultural environments. By acknowledging these challenges, the review strives to provide a balanced and comprehensive understanding of the field while identifying areas for further research and improvement.

1.4. Objectives of This Review

- To figure out the microorganisms responsible for the decomposition of hazardous substances in the agricultural environment.
- To ascertain the extent to which these bacteria break down the pollutants that pose a risk to the agricultural environment.
- To identify the factors influencing the efficiency of microbial digestion of chemicals which constitute a risk to agricultural activities and the environment.
- To find gaps in the current research on the microbial breakdown of pesticides that can cause potential hazards to the agricultural industry.

1.5. Scope and Organization

This comprehensive review focuses on the microbial degradation of pesticides in agricultural environments, covering mechanisms, factors, biodiversity, and technological developments. It explores enzymatic pathways, reactions, and key enzymes involved in pesticide transformation. Environmental elements including humidity, pH, temperature, organic matter, and nutrients are examined for their influence on microbial degradation. The role of microbial biodiversity, including community dynamics and adaptation, is explored. Agricultural practices, soil type, and climate are assessed for their impact on microbial pesticide degradation. The organization of this review paper is Section 2 “The literature review section provides an overview of microbial degradation mechanisms, enzymatic pathways, and factors influencing pesticide transformation”. Section 3 “The application of microbial degradation of pesticides in agricultural environments:”, Section 4 “The findings and discussion section present analyzed studies, Section 5 “concludes the paper”.

2. Microbial Degradation of Pesticides in Agricultural Environments

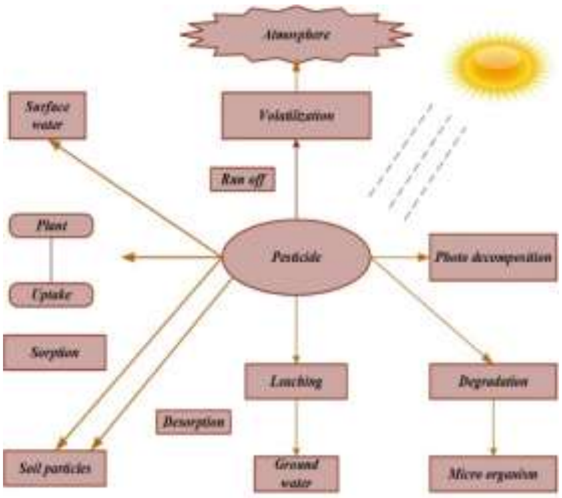

Figure 2. Microbial degradation of pesticides

Agriculture uses pesticides frequently, although raises concerns about their environmental impact and health risks. Microbial degradation, carried out by microorganisms, offers a natural solution for pesticide breakdown and detoxification. Microorganisms possess enzymes and metabolic pathways that transform pesticides into simpler forms, reducing their persistence in the environment. Mechanisms such as hydrolysis, oxidation, reduction, and conjugation are facilitated by specific enzymes targeting different functional groups in pesticides. Environmental conditions, co-substrates, nutrient availability, pesticide concentration, and biodiversity influence microbial degradation. A diverse microbial community enhances degradation capacity and ecosystem resilience, enabling the breakdown of pesticides in agricultural environments.

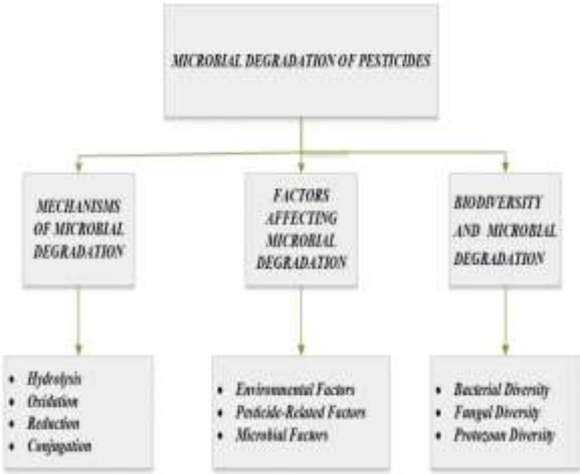

Figure 3. Microbial degradation of pesticides in mechanism, factor, biodiversity

2.1. Mechanisms Of Microbial Degradation

Microbial degradation is a difficult procedure involving microorganisms, both enzymes and metabolic pathways to break down organic compounds, including pesticides. It performs a crucial role in environmental remediation and addressing pesticide residues in agriculture. Two main types of microbial degradation aerobic and anaerobic, occur in the presence and absence of oxygen, respectively. Aerobic degradation relies on oxygen-dependent enzymes such as monooxygenases, dioxygenases, and hydrolases to break down pesticides into smaller fragments. Anaerobic degradation, on the other hand, utilizes specialized enzymes like reductive dehalogenases and reductive dehydrogenases to remove functional groups from pesticides under oxygen-deficient conditions. Microorganisms can also employ co-metabolism, utilizing existing metabolic pathways to transform pesticides. The process of microbial degradation can occur intracellularly or extracellularly, with enzymes acting within microbial cells or being secreted into the surrounding environment. Understanding these mechanisms is crucial for developing effective strategies to manage pesticides and protect the environment.

Several methods had been used to break down pesticides in soil; including included physical, chemical, and physical-chemical deterioration that eventually resulted in secondary pollution [26, 27, and 28]. The amount of use of microbial degradation has increased recently due to the reality that pesticides were mostly used as microbial nutrients, which eventually broke down into small molecules like CO_2 and H_2O. The method employed was known as an enzymatic reaction, and it engaged first the compound entering the body of a microorganism through a specific route, followed by a series of physiological and biochemical responses executed by different enzymes, that subsequently resulted in the pesticide being completely broken down or separated down into smaller molecular compounds that are either non-toxic or less toxicity [29, 30].

The degradable procedures consisted of oxidation (hydroxylation reactions, which includes aliphatic, aromatic, and N-hydroxylation; epoxidation; N-oxidation; P-oxidation; S-oxidation; oxidative dealkylation; reductive dehalogenation; reduction of nitro group); the hydrolysis (some esters, like thiophosphate and thiocarbamate, etc., which have ester bonds that can be hydrolyzed by bacteria); dehydrogenation, dehalogenation, decarboxylation, condensation, synthesis, and many more [31,32]. By decomposing down organic macromolecules into smaller, non-toxic ingredients, the bacteria would avoid secondary pollution. Research has shown that the primary mechanisms responsible for the further degradation of pesticides and their intermediate byproducts were mineralization and co-metabolic processes [17, 33, 34, and 35].

There were actually three components to the entire deterioration mechanism. First, the dynamic equilibrium procedure referred to as target adsorption occurred on the surface of the cell membrane and was significant. Second, the target entered the cell via a hole in the cell membrane's surface, and the rate and efficiency of penetration were associated with the target isomerism's molecular architecture. Thirdly, an immediate enzymatic reaction took place out in the membrane by the exotic foods target [36].

2.1.1. Hydrolysis

Hydrolysis is one of the key processes that contribute to the microbial degradation of organic compounds, including pesticides. It is a process in which water molecules break down chemical bonds within the pesticide molecules, leading to their decomposition. During hydrolysis, microorganisms produce and release specific enzymes known as hydrolases. These enzymes catalyze the cleavage of chemical bonds through the addition of water molecules. The hydrolytic reaction can occur at various functional groups within the pesticide molecule, such as ester, amide, or glycosidic bonds, resulting in the breakdown of the pesticide into simpler, less toxic compounds. The hydrolysis mechanism is particularly important for the degradation of pesticides with ester functional groups, as they are susceptible to enzymatic hydrolysis. For instance, esterase Ester bond hydrolysis is known to be facilitated by enzymes commonly found in many pesticide formulations. By breaking down these ester bonds, microorganisms effectively neutralize the pesticide and convert it into less harmful metabolites**.**

Wilson 2011 [37] assessed the cellulose via enzymatic hydrolysis bacteria as a critical global carbon cycle phase. Even with its widespread presence, only a few microbes can break down cellulose, most likely because it is found in resistant cell walls. Due to the wide variety of plant cell walls that serve as their natural substrate, cellulolytic organisms, and cellulases are also exceedingly diverse. Despite a wealth of knowledge about the bovine rumen at the time, the microbial ecology of cellulose degradation in any environment was still not fully known.

Sun *et al*. 2021 [38] determined how biological degradation and acid-based hydrolysis affected the ensiling procedure as a pre-treatment for making biogas. For dry matter (DM) concentrations of 20, 50, and 80 g/kg, lactic, acetic, and butyric acid were applied to wilted maize stover. in nine different treatments, and the mixture was subsequently ensiled for 60 days. The three treatments including 20 g/kg of DM of organic acid showed synergistic consequences of biological degradation and acid-based hydrolysis, resulting in an LDR of 26%–31% for lignocellulose and an increase in the Compared to the raw material, there is a 10%–13% biomethane potential (BMP). However, despite the biological degradation being nearly entirely stopped in the treatments that included an addition of 80 g/kg of organic acid, LDR remained between 20% and 24%, while BMP increased by 6% to 8% in raw material prices.

Theriot and Grunden 2011[39] assessed certain nerve agents and insecticides, toxic organophosphorus (OP) chemicals can be broken down by specific groups of microbial enzymes. Organophosphorus acid (OPA) and organophosphorus hydrolase (OPH hydrolase (OPAA), which have both been characterized by a variety of species, are now the most researched and potentially significant OP-degrading enzymes. Here, we give a summary of the experimental knowledge currently available on OPH and OPAA, including information about their structures, substrate selectivity, and catalytic characteristics.

Barth *et al*. 2015 [40] examined PET post-consumer biocatalytic hydrolysis as a feasible plan to recycle plastic in a sustainable manner procedure. By using reversed-phase HPLC, the effect When PET is broken down by intermediate hydrolysis products, a polyester hydrolase from called $TfCut_2$ is produced. Thromboid fusca was examined. Mono-(2-hydroxyethyl) terephthalate (MHET), bis-(2-hydroxyethyl) terephthalate, and ethylene glycol among others, all contributed to the formation of the enzyme hydrolyzed nanoparticles made from PET sheets as substrate. A model for PET degradation was used to predict the initial reaction rates and examine them kinetically. Competitive inhibitors with identical binding constants were found to be BHET and MHET.

Bhardwaj *et al.*2013 [41] assessed plastics are being released carelessly and regularly on purpose, which is to blame for the rising environmental contamination. Researchers create low-cost, effective technologies and eco-friendly remedies that can cut back on or even get rid of plastics. Microbial enzymes are one of the most effective biological agents for the biodegradation of plastics. More enzymes are actively biodegraded by fungi than by bacteria. The rate of induced biodegradation of plastics by bacterial and fungal enzymes as well as the mechanism of biodegradation are the main topics of this review. Significant surface changes in plastics point to their biodegradation. Table 1 shown in below.

Table 1: Review of mechanisms of microbial degradation by using hydrolysis

Citation no.	**Author**	**year**	**Techniques used**	**Limitations/ futures scope**
[37]	Wilson	2011	Genomic and metagenomic techniques	The cellulose degradation includes the difficulty of diverse microbiological groups involved and the challenge of culturing and characterizing unculturable cellulolytic microorganisms, necessitating advancements in molecular techniques for a comprehensive understanding.
[38]	Sun *et al.*	2021	Ankom Technology	The research is needed to validate the findings using different feedstocks and to consider additional parameters to optimize the ensiling process for efficient biogas production.
[39]	Theriot and Grunden	2011	Hydrolysis mechanism	The research and validation to investigate the relevance of the findings in larger contexts and actual applications, as well as to corroborate the proposed processes.
[40]	Barth	20	Titration	That it

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	et al.	15	and Turbidimetric analysis	focused on the influence of specific intermediate hydrolysis products, namely BHET and MHET, on the degradation of PET by TfCut2. The findings may not fully represent the inhibitory effects of other potential intermediate products that could be present in real-world PET recycling processes.
[41]	Bhardwaj	2013	Mechanism of enzymatic biodegradation	Environmental conditions can vary significantly, and other factors such as temperature, the presence of coexisting substances, and microbial activity can influence the degradation of sulphonamides.

2.1.2. Oxidation

Oxidation is another significant mechanism involved in the microbial degradation of organic compounds, including pesticides. It is a process in which microorganisms utilize enzymes to introduce oxygen molecules into the pesticide molecule, resulting in the formation of oxidized products. Microorganisms employ a variety of enzymes called oxidoreductases to catalyze oxidation reactions. These enzymes, such as monooxygenases and dioxygenases, facilitate the transfer of oxygen atoms or electrons to the pesticide molecules, thereby altering their chemical structure.

Cho *et al.* 2010 [42] assessed numerous enzymes from bacteria, fungi, and plants that are taking part in the breakdown of toxic organic contaminants. The energy for the ecologically friendly and commercially successful biotechnology process known as bioremediation is provided by microbial enzymes. The research in this field will help create cutting-edge bioprocess technology to lessen the toxicity of the pollutants and also produce new beneficial compounds. Bioremediation-related enzymes such as oxidoreductases and hydrolases have had their mechanisms thoroughly researched. This research makes an effort to give specific details on the enzymes from diverse microorganisms engaged in the biodegradation of a variety of pollutants, applications, and recommendations needed to get around the obstacles to their effective use.

Zhuang*et al.* 2015 [43] examined that in both natural and artificial microbial communities, minerals made of conductive iron oxide can promote the Syntrophic methanogenic metabolism breakdown of organic materials, including ethanol, propionate, and butyrate. Direct interspecies electron transfer (DIET), which is the driving force behind this improved syntrophy, is fueled caused by bacteria transferring electrically conductive minerals to carry metabolic electrons. Here, they investigated whether the methanogenic breakdown of benzoate, a frequent step in the anaerobic metabolism of aromatic compounds, might be stimulated by conductive iron oxides (hematite and magnetite).

Xu *et al.* 2016 [44] analyzed the studies on peroxymonosulfate (PMS) oxidation, which was used to remove bisphenol A (BPA) from an aqueous solution. $CuFe_2O_4$ magnetic nanoparticles (MNPs) were used to activate this process. The effects of anions (Cl, F, ClO_4, and H_2PO_4), Concentration of PMS, CuFe2O4 dose, initial pH, beginning BPA level, and manner of catalyst addition on BPA degradation were examined. EPR, or electron paramagnetic resonance, was employed. To confirm the production of reactive radicals, primarily hydroxyl radicals. based on the findings of the radical identification tests and the XPS analysis, potential pathways for the militant generation of the $CuFe_2O_4$/PMS system are presented. The mineralization of bisphenol A is thought to be caused by surface-bound molecules rather than by surface-catalyzed redox cycles involving both Fe (III) and Cu (II), free radicals.

Wang and Wan 2015 [45] assessed and compared various technologies for the Microbial conversion treatment and disposal of spent radioactive resins including immobilization (like cementation, bituminization, and plastic solidification), advanced oxidation processes (like incineration, pyrolysis, acid boiling degradation, the Fenton or Fenton-like reaction, supercritical water oxidation, and plasma technology), as well as super compaction. The nuclear industry makes considerable use of ion exchange resins to purge fuel components of any potentially radioactive impurities, such as neutron activation products and fission products. The wasted radioactive ion exchange resins were created when the nuclear plants in the nuclear industry were in operation. Table 2 shown in below.

Table 2: Review of mechanisms of microbial degradation by using oxidation

Citation no.	**Author**	**year**	**Techniques used**	**Limitations/ futures scope**
[42]	Cho *et al.*	2010	Inactivation mechanism	The findings and conclusions regarding inactivation mechanisms may not be directly applicable to other microbial species, and further research involving a broader range of microorganisms would be beneficial.
[43]	Zhuanget *al.*	2017	Inactivation mechanism	Different AOPs might be compared to one another to shed light on the most efficient way to degrade fluoroquinolones.
[44]	Xu *et al.*	2016	citrate combustion method	A comparative analysis could give further insight into the effectiveness and efficiency of the $CuFe_2O_4$/PMS system about alternative methods.
[45]	Mbadinga, *et al.*	2011	Degradation mechanism	That it offers an overview and comparison of various technologies without going into individual case studies or experimental data, which might restrict the depth of understanding and judgment of the efficacy of each technology.

2.1.3. Reduction

Microbial reduction is a key mechanism in the degradation of pesticides, involving the addition of electrons to transform them into less toxic forms. Reductases are specific enzymes used by microorganisms to facilitate reduction reactions, targeting functional groups like nitro, azo, or halogenated groups. Anaerobic environments are particularly important for microbial reduction, where specialized enzymes such as reductive dehalogenases and reductive nitroreductases are employed by bacteria and archaea. These enzymes remove electron-withdrawing groups, detoxifying pesticides and converting them into less harmful compounds. Factors such as pH, temperature, electron donor availability, and microbial community composition influence microbial reduction in different environments. Understanding these mechanisms and factors is crucial for the development of effective pesticide bioremediation strategies.

Semova *et al.*2012 [46] analyzed that maintaining energy balance depends on controlling intestinal dietary fat absorption. While the host's energy balance is impacted by intestinal microbiota, it is less known how these microorganisms contribute to metabolic processes of dietary fat outside of the gut and intestinal absorption. They discovered that the microbiota increases FA absorption also, lipid droplets (LD) generation in the liver and intestinal epithelium by delivering gnotobiotic zebrafish hosts using fluorescent fatty acid (FA) analogs for in vivo imaging. The number of epithelial LD is increased by microbiota in a diet-dependent way. hosts in gnotobiotic zebrafish using fluorescent fatty acid (FA) analogs were caused by the presence of food. Firms and their goods from enriched diets were sufficient to increase the number of epithelial LDs, whereas other bacterial kinds increased LD size.

Huang *et al*. 2011 [47] investigated the treatment of hydraulic retention of synthetic wastewater with low strength durations of 12, 10, and 8 h (HRTs), There were a total of three 6-L submerged anaerobic membrane bioreactors set up with solids retention durations (SRTs) of 30, 60, and infinite days. At all operating conditions, total COD removal efficiencies of more than 97% were attained. At an infinite SRT, the highest biogas generation rate was 0.056 L CH_4/g MLVSS d. Due to a higher organic loading rate or increased methanogenic dominance, a shorter HRT or longer SRT boosted biogas generation. Reduced HRT exacerbated membrane fouling by promoting biomass development and the buildup of soluble microbial products (SMP). Fouling was also adversely impacted by a decrease in the carbohydrate-to-protein ratio.

Angelidaki *et al*. 2011[48] examined the technique of bio methanation. The conversion of anaerobic bacteria converting organic material to biogas circumstances is referred to as bio methanation. The three main physiological categories of microorganisms involved are methanogenic archaea, bacteria that oxidize organic acids, and fermenting bacteria. Through a cascade of metabolic transformations to methane and carbon dioxide, microorganisms break down organic materials. The process depends on syntrophic interactions between hydrogen scavengers and producers (acetogens) (Hom acetogenins, methanogens that produce hydrogen.). For the best process design, setup, and efficient evaluation of economic viability, it is crucial to determine the practical and theoretical methane potential.

Zhang*et al.* 2019 [49] looked at electroactive bacteria used in microbial fuel cell (MFC) technology to break down organic compounds and generate bioelectricity. MFC is a method that might be effective for treating wastewater while simultaneously producing electricity. Energy savings, a decrease in sludge volume, and the production of bioenergy are among MFC's key benefits for treating wastewater. Significant improvements in MFC performance have been accomplished during the last 20 years. But because of their expensiveness and poor power densities, MFCs still have a long way to go before they can be used in practical applications. For independent MFC devices, further advancement is getting more challenging. Comparing hybrid systems to solo MFCs, hybrid systems are more promising. This thorough and cutting-edge assessment covers a variety of systems linked with MFCs that use various operating principles, reactor designs, and operational parameters, as well as their implications on system performances. Table 3 shown in below,

Table 3: Review of mechanisms of microbial degradation by using reduction

Citat ion	Autho r	ye ar	Techni ques	Limitations/ futures

no.			used	scope
[46]	Semova *et al.*	2012	Lipid Absorption	To better comprehend the relevance to human physiology, more study is required to confirm these findings in mammalian models and human participants.
[47]	Huang *et al.*	2011	analytical method (APHA, AWWA - WEF).	The research did not investigate the long-term stability and sustainability of the submerged anaerobic membrane bioreactors (SAnMBRs) under different operating conditions, which could be crucial for practical implementation
[48]	Angelidaki *et al.*	2011	Hydrolysis mechanism	The presence of inhibitory substances, such as heavy metals or certain chemicals, in the feedstock, can negatively impact microbial activity and methane production. Proper monitoring and management of the feedstock composition and quality are essential to overcome these limitations and ensure efficient biomethanation.
[49]	Zhang *et al.*	2019	MFC	The information on the practical constraints, technical difficulties, and potential drawbacks of implementing these hybrid systems would enhance the understanding of the challenges faced in the practical application of MFCs. Future research should focus on addressing these limitations to facilitate the wider adoption and practical deployment of MFC-hybrid systems.

2.1.4. Conjugation

Conjugation is a mechanism of microbial degradation that involves the transfer of plasmids containing pesticide-degrading genes between bacteria. Through physical contact and the formation of a pilus, a donor bacterium transfers the plasmid to a recipient bacterium. The recipient bacterium then gains the ability to produce enzymes encoded by the plasmid, allowing it to degrade specific pesticides. Conjugation facilitates the spread of pesticide-degrading capabilities within microbial communities, promoting adaptation and survival in pesticide-contaminated environments. This mechanism is not limited to specific bacteria or pesticides and can enhance the overall degradation of microbiological communities' potential. The versatility of conjugation enables the dissemination of degradation capabilities for different classes of pesticides, contributing to effective pesticide remediation.

O'Shea*et al*. 2012 [50] revealed the intricate and diverse ways that gut microbes achieve their related health benefits. The particular microbial composition of the human gastrointestinal tract (GIT) is noteworthy in this regard. offers a virtually limitless potential supply of bioactive compounds which may have an impact on human health either directly or indirectly. Just two pharma biotic compounds that may support probiotic functioning in the mammalian GIT are bacteriocins and fatty acids. bacteriocin synthesis is thought to give generating strains a competitive edge within complicated microbial ecosystems. It is also well known that intestinal bacteria produce a wide variety of fatty acids that promote good health. It has been demonstrated that specific strains of intestinal bifidobacterial create v

Shrestha*et al.* 2014 [51] Succeed Photo crosslinking dentin-collagen enabled the functionalization of bioactive polymeric chitosan, rose Bengal, and CSRBnp nanoparticles to provide antibiofilm properties and uphold structural integrity. Even in the presence of bovine serum albumin, CSRBnp they're significantly more antibacterial active and less toxic to fibroblasts. Following photodynamic therapy, CSRBnp adhered to the membrane, made it permeable to the surface of the bacterial cell, and led to cell lysis. Enterococcus facials biofilm viability was decreased, and the structure of the biofilm was disrupted, by photoactivated CSRBnp. The mechanical strength and resistance to degradation of dentin-collagen they're dramatically increased by the incorporation of CSRBnp and photocrosslinking (P b 0.05).

Varkouhia *et al*.2011 [52] investigated that despite continual developments in delivery systems, the creation of procedures for the accurate and efficient administration of a class of targeted therapeutic compounds in biological therapies like protein and gene therapy remains a problem. The primary channel for cellular uptake of DNA, siRNA, proteins, and other biological agents is the endocytic pathway. These substances get caught in endosomes and are digested by certain lysosomal enzymes. Both bacteria and viruses are pathogens that pierce target cell membranes and evade the endosomal process in various ways. Endosomal escape has been postulated to be facilitated by a variety of mechanisms, including pore development proton-able groups' ability to buffer pH in the endosomal membrane and their ability to fuse with the lipid bilayer of endosomes. several bacterial and viral Proteins that are a part of this pathway have been found.

Combalbert and Hernandez-Raquet 2010 [53] investigated the natural sex hormones generated by both humans and animals including estrone (E1), 17-estradiol (E2), 17-estradiol (E2), and estriol (E3). There are also some synthetic estrogens used for contraception, such as 17-ethinylestradiol (EE2). At nanograms per litter, these substances can cause endocrine disruption in living things. Estrogens are secreted in urine and faces by both people and animals, and they are released into ethe environment via sewage treatment plant (STP) discharges and manure disposal facilities. Hormone removal in STPs is influenced by the type of treatment method used as there as many factors, including the hydraulic and sludge retention times. Animals indeed create a lot of hormones, and these hormones end up in the manure that is often distributed on land. Animal hormones found in the trash could therefore spread these pollutants to the soil.

Menon *et al.* 2018 [54] investigated selenium nanoparticles now hold great potential given their fascinating features compared to other forms of selenium in the field of medicine. Comparatively speaking, they perform better than selenite (SeO_3^{-2}) and selenate (SeO_4^{-2}) compounds as anticancer, nontoxic, and biocompatible agents. Apoptotic pathway invasion and cell cycle arrest, whereby Apoptotic pathway invasion and cell cycle arrest, whereby ultimately result in the obstruction of other pathways, is the main cause of SeNps' anticancer effects. Selenium, an essential component of enzymes like glutathione peroxidase (GPx) and other seleno-chemical substances, protects the tissues from cellular damage caused by ROS and functions that represent the redox center's functional division, which may help chemotherapy work better.

Fuentes*et al.*2014 [55] approached Bioremediation as a practical and sustainable method for treating hydrocarbon-polluted soils and coasts. Even though longer durations are often needed to be compared to physicochemical approaches, full pollutant degradation can be accomplished and no additional containment of the contaminated matrix is necessary. By incorporating entering a molecule of inert hydrocarbon with a small amount of oxygen and directing intermediates into the main catabolic pathways, microbial aerobic degradation of hydrocarbons is accomplished. This process allows bacteria that break down hydrocarbons to better comprehend and utilize their metabolic potential, which forms the basis for improving the fitness of microbes and enhancing hydrocarbon removal. Nevertheless, microbial populations as a whole have a significant impact on hydrocarbon contamination incidents. It is crucial to comprehend how microorganisms react and change in response to pollution and clean-up during biodegradation. Table 4 shown in below.

Table 4: Review of mechanisms of microbial degradation by using conjugation

Citation no.	**Author**	**year**	**Techniques used**	**Limitations /futures scope**
[50]	O'Shea et al.	2012	Transformation mechanism	Further establishing the function of certain probiotics in health and illness would necessitate more thorough research on the mechanisms of action of pharma biotic compounds, variables affecting the metabolic activity of probiotics in vivo, as well as thorough human studies.
[51]	Shrestha*et al.*	2014	Antibacterial Mechanism	The effectiveness of CSRBnp against other bacterial species commonly found in infected teeth should be explored to assess its broad-spectrum antimicrobial potential. Furthermore, the long-term stability and durability of the dentin-collagen photocrosslinking approach should be assessed to determine its feasibility as a long-lasting treatment option for

				infected teeth.
[52]	Varkouhi *et al*.	2011	Transformation mechanism	Further research and evidence are needed to validate the efficacy and safety of these mechanisms and agents such that medicinal substances can be delivered effectively and precisely in biological treatments.
[53]	Huddleston	2014	Evolution of horizontal gene transfer	The comprehension of the existing difficulties in establishing effective and focused delivery of targeted therapeutic medicines might be improved by further investigation of these constraints.
[54]	Combalbert and Hernandez-Raquet	2010	Mechanisms for estrogen removal	The provided information lack of specific details and examples regarding the hormonal metabolic pathways
				and their microbial breakdown.
[55]	Fuentes *et al*.	2014	Bioremediation technique	The article makes reference to the genetic and metabolic mechanisms behind hydrocarbon breakdown in model bacteria as well as the contribution of certain bacterial populations to the reaction to oil spills, but it does not offer any hard data or proof to back up these claims.

2.2. Factors Affecting Microbial Degradation

Microbial degradation of pesticides is influenced by various factors, including microbial community composition, environmental conditions, pesticide properties, co-substrate and nutrient availability, pesticide concentration, interactions with other chemicals, and time and degradation history. The composition and diversity of the microbial community impact pesticide degradation by providing a wider range of enzymatic capabilities. Environmental conditions such as temperature, pH, moisture, and oxygen levels affect microbial activity and enzyme function. Pesticide properties, including structure, solubility, and persistence, determine their degradability. Co-substrates and nutrient availability support microbial growth and metabolism. Pesticide concentration, interactions with other chemicals, and degradation history can further influence degradation rates. Considering these factors is crucial for optimizing microbial degradation and developing effective strategies for pesticide remediation, thereby promoting sustainable approaches to managing pesticide residues in the environment.

2.2.1. Environmental Factors

Microbial degradation, also known as the process of biodegradation occurs when microorganisms transform organic molecules into simpler forms, ultimately recycling them back into the environment. Several environmental factors can influence the rate and efficiency of microbial degradation. Microbial degradation is highly temperature-dependent. Different microorganisms have specific temperature ranges at which they thrive. Generally, higher temperatures increase the rate of microbial activity and degradation. However, extreme temperatures can also negatively affect microbial activity and enzyme function.

The degradation would be influenced by a number of variables, including moisture, temperature, salinity, pH, nutrition, carbon dioxide, oxygen, quantity of substrate, surfactant being used etc. [56, 57, 58, and 59]. An appropriate pH, temperature, and substrate concentration were necessary for bacteria or their enzymes [60]. The concentration of benzene rings in PAHs significantly affected how quickly they could be broken down by microbes. The environment contained two rings and tricyclic chemicals (naphthalene, phenanthrene, anthracene, fluorene, etc.) that could be mineralized by microorganisms using PAHs as their single carbon source in a relatively brief period of time. However, it was challenging to decompose the high molecular weight, stable four-ring and other multi-ring PAHs due to their long-term stability in the environment. However, these substances could be destroyed down by the metabolism of the white rot fungi [61].

Varjani 2017 [62] analyzed Natural microbial biodegradation activity used in bioremediation, a key technique for cleaning up petroleum hydrocarbon-polluted settings. Microorganisms that use petroleum hydrocarbons are found throughout the environment. They eliminate toxins from the environment by naturally biodegrading them. It is economical and environmentally favorable to remove petroleum hydrocarbon contaminants from the environment by using oleophilic microbes (individual isolates or consortiums of microorganisms). To accelerate the decomposition of contaminants from hydrocarbons in petroleum, microbial biodegradation uses microorganisms' enzyme catalytic activity.

Buyer *et al.*2010 [63] claimed that the microbial populations in the soil and rhizosphere are perhaps impacted by agroecosystems, climate, kind of plants, soil, and management practices. Three years of field research revealed the managerial environmental aspects influencing biomass and community structure of microbes. The following theories they're examined: (1) The makeup of the soil's microbial population is impacted differently by the roots and shoots of various types of cover crops, and (2) Differences in temperature and moisture differences between cover-cropped and polyethylene-covered treatments contribute to treatment effects on soil makeup of the microbiological ecosystem. By analyzing the fatty acids in phospholipids, microbial biomass estimation, and community composition they're quantified. Microbial biomass was increased by every cover crop treatment, including root and shoot alone.

The two most significant parameters influencing both the growth and development of bacteria were temperature and humidity [64]. Zhu et al. looked at how bacteria Ralstonia and Pickettii broke apart and mineralized biaryl compounds in soil and compost. They observed that, in the right soil moisture conditions, nonionic surfactants such as tween 80 can improve the bacteria's uptake of biaryl compounds like biphenyl and 4-chlorobipheny [65, 66]. When decomposition was combined with PAH-contaminated soil, Gupta et al. decided that the effects of organic substrate content on pesticide breakdown during composting outweighed the impact of bacterial content. When bacteria broke away pesticides through co-metabolism, consumption became increasingly important because they were carbon- and energy-negative organisms that needed outside supplies of both [67, 68].

Brockett *et al*. 2012 [69] determined how environmental factors shape microbial communities and how these communities' organizational and functional elements interact, and affect the rates of important soil processes, although soil microorganisms are essential to the soil mechanisms that control nitrogen availability and forest ecosystem productivity. Here, they evaluate the composition of soil microbiota communities inside different forest types and across seven mature, undisturbed forest types in British Columbia and Alberta across a variety of regional temperatures. The composition of the soil's microbial communities and the overall biomass of those organisms they're investigated using phospholipid fatty acid analysis; potential extracellular enzyme activities revealed the capability of each stratum's soil microbial population at each location.

Kumar*et al*. 2018 [70] analyzed the industrialization-related pollution of groundwater, soil, and surface water together with hazardous compounds as one of the key global concerns for human sustainability. To advance sustainable growth while having little negative environmental impact, Hazardous organic and inorganic pollutants need to be removed from contaminated areas. It has been found that the traditional method of treating contaminated soil, sediment, and water is impractical because it is expensive and causes secondary pollution. In the presence of polluted soil, sediment, surface water, and groundwater, microorganisms are created. in this developing green technology to speed up the breakdown of and/or removal of inorganic and organic contaminants. Broadly speaking, there are two types of bioremediation technologies: Both in situ and ex-situ bioremediation are available. Ex-situ bioremediation entails the removal of the contaminated material after it has been treated elsewhere, whereas in-situ bioremediation treats polluted substances in the same location.

Riggs *et al*. 2013 [71] Analysed globally and revealed that human activity has greatly increased nutrient availability and deposition, especially for nitrogen (N). The impact of enrichment on this sizable, heterogeneous carbon (C) pool, referred to as soil organic matter (SOM), remains unknown. Physical, chemical, and biological mechanisms that define the SOM pool mean residence duration are all influenced by nitrogen, including breakdown through mineral association and aggregate occlusion. They were able to close this knowledge gap by analyzing five grassland experiments in the Central Great Plains of the US that are a member of the Nutrient Network and have been fertilized for three or five years to examine the impact of N addition on different SOM pools. Additionally, with the addition of N, soil aggregation and C blockage in substantial macro-aggregates tended to rise.

Lu 2015 [72] investigated tropical and subtropical regions of Asia, aubergines (Solanum melongena L.) are a significant and extensively farmed vegetable crop. The top three nations in the world for eggplant production are India, China, and Egypt. The attempts to explain the pesticide residues found in the soil, water, and eggplant fruits in the Sta. Maria, Pangasinan, eggplant farms. For the cross-sectional study design, the Sta. Maria and Pangasinan eggplant fields were randomly selected. Examination of multi-Pesticide traces in the aubergine fruits, water, and soil was done using gas chromatography (Shimadzu).

Pisa *et al*. 2015 [73] examined the state of understanding of the potential effects of fipronil and neonicotinoid pesticides in the terrestrial, river, and marine habitats on non-target invertebrate species. Since honeybees (Apis mellifera), an essential pollinator, are the most researched non-target invertebrate species, a sizable portion of the assessment's focus is on how much is known about sublethal effects on honeybees. The sections "other invertebrates," "Lepidoptera" (moths and butterflies), "Lumbricidae" (earthworms), "Apoidae sensu lato" (bumblebees, solitary bees), and "other invertebrates" evaluate the research that has been done on the other terrestrial species.

Alshemmari *et al*. 2021 [74] evaluated the pesticide levels of surface soil samples from the Kuwaiti farmland Sulaibiya. The research also looked at estimating health risks for adults and kids based on residual concentrations. In the current investigation, the average concentration of OCPs (the total amount of organochlorine pesticides) was 3062 pg/g. Compared to other places in the world, the residual concentration of OCPs was other. A, B, and D sites among the 11 examined locations shorthead greater quantities of OCPs. Each kind of organochlorine pesticide (OCP) has a varied distribution pattern in Sulaibiya, indicating nonsimultaneous0 usage of different groups of OCPs in this region.

Serra *et al.*2020 [75] depicted that Chemical soil pollution caused by human activity is a major issue for the sustainability of agricultural production and ecological processes that are mediated by natural plant biodiversity. Multi-level and multi-scale techniques are necessary to comprehend the intricate consequences of soil contamination. Agricultural xenobiotics are exposed in field margins and vegetative filter strips due to events involving soil contamination, drift, run-off, and leaching that follow chemical applications to populations of agri-environmental and non-target plants. In the context of a long-term ecological research network, a field-scale investigation of the dynamics of plant-pesticide interactions in vegetative filter strips was carried out in the agricultural setting of northern Brittany (France).A major reduction in pesticide use was achieved between the field and the riparian areas thanks to vegetative filter strips. contamination on a large scale. Table 5 shown in below.

Table 5: Review of Factors Affecting Microbial Degradation Environmental Factors

Citation no	Author	year	Techniques used	Limitations/futures scope
[62]	Varjani	2017	Bioremediation technique	The article mentions "new insights obtained during the past couple of years" without providing specific references or details, making it difficult to assess the currency and reliability of the information presented.
[63]	Buyer *et al.*	2010	Phospholipid fatty acid analysis Statistical analysis	It focused on a specific agroecosystem (tomato production) and may not fully represent microbial communities in other agricultural systems or environments.
[69]	Brockett *et al.*	2012	PLFA analysis Enzyme analysis	The understanding of seasonal fluctuations and long-term dynamics was limited since it only examined microbial communities and soil activities at two distinct periods (spring and summer).
[70]	Kumar *et al*	2018	Bioremediation mechanism	Bioremediation is a flexible, environmentally acceptable method of treatment and a quickly expanding field of environmental rehabilitation.
[71]	Riggs *et al*	2015	bioremediation mechanism	Their knowledge of soil C sequestration in various ecosystems

				might be aided by future multi-study locations that change a fundamental state variable (such as the parent material of the soil) that influences SOM stabilization to explore the effects of N.
[72]	Lu	2015	The quality control method used for this analysis	Pesticide levels in aubergine fruits during different developmental phases and up until the point when they are offered to consumers at retail could be examined in future research variations, as could the number of insecticide residues based on farmers' traditional methods of applying pesticides.
[73]	Pisa *et al*.	2015	Degradation techniques of pesticides	The study makes no particular suggestions or offers any alternatives to lessen the harmful effects of fipronil and neonicotinoid insecticides on non-target invertebrates.
[74]	Alshemari*et al*.	2021	Multivariate statistical analysis	This study is that it focuses on a specific agricultural field in Sulaibiya, Kuwait, which may limit the generalizability of the findings to other regions or soil types. Additionally, the study does not investigate the long-term effects or potential environmental impacts of pesticide residues in the soil.
[75]	Serra *et al*.	2020	Quantitative analysis	It focuses on a specific agricultural landscape in northern Brittany, France, which may limit the generalizability of the findings to

				other regions with different soil and climatic conditions.

2.2.2. Pesticide-Related Factors

Pesticide-related factors encompass various aspects of pesticides, including their chemical composition, persistence, toxicity, mobility, volatility, application rate, formulation, resistance, synergistic effects, and regulatory measures. The chemical composition determines the pesticide's mode of action and potential environmental and health impacts. Persistence refers to its ability to persist in the environment, while toxicity determines its potential harm to organisms. Mobility and volatility affect their movement in the environment and the potential for water and air pollution. The application rate and formulation impact efficacy and off-target effects. Pesticide resistance can develop in pests, reducing effectiveness. Synergistic effects can occur when multiple pesticides are used together. Regulations and safety guidelines aim to ensure responsible pesticide use and minimize risks to the environment and human health. Considering these factors is crucial in understanding and managing the impact of pesticides on ecosystems and human well-being.

Yadav 2010 [76] reported that many pesticides and other chemicals are not biodegradable; instead, they can ingest food through bioaccumulation and eventually endanger human and animal health. Humans are exposed to pesticides through ecosystems during crop and agricultural practices, food eating, air inhalation, and other activities. Crop productivity might decrease by up to a third without the use of agricultural chemicals (such as fungicides and insecticides) or pesticides, rodenticides, and herbicides), and food costs could rise by as much as 75%. Even though India's usage is little around 0.5 kg/ha, 51% of food items have pesticide residues. Based on tests done on lab animals, several indicators (such as oral and dermal LD50) are used to determine how toxic a pesticide is. They mostly affect receptors. Acute and long-term harm to the immune and endocrine systems, birth, lung injury, reproductive system impairment, deformities, and cancer are just a few of the negative health impacts.

Fuentes*et al*. 2010 [77] investigated that due to high toxicity, long environmental persistence, and propensity for bioaccumulation, organochlorine insecticides are well-known. Remains from its intensive use are still present in the environment in northeastern Argentina. Actinomycetes have considerable potential for microbial breakdown, a crucial step in pesticide bioremediation. Except for one, all of the isolated bacteria belonged to the genus Streptomyces. The microbe and the pesticide (lindane, chlordane, or methoxychlor) present both affected bacterial growths. Chlordane results in the greatest growth and pesticide clearance rates.

The rate and efficiency of pesticide microbial degradation were impacted by the pesticides' own characteristics, comprising their molecular size, physical structure, number and variety of substituents, substituted properties, and location [78, 79, and 80]. On a comparative basis, the low molecular weight chemical became more biodegradable than the polymer complex in nature. Although the composite and polymer revealed greater resistance to biodegradation, the one with a more plain space structure broke down more rapidly [81].

Herbicide use has become an essential component of agricultural production, which has led to plenty of environmental pollution issues rising to light, especially the danger to human health and the high pesticide content of agricultural and non-agricultural products. A great deal of the pollutants that are present today are synthesized biological heterogonous organic substances that are not found in nature, and they frequently display significant resistance to microorganism destruction. This introduced a new problem for the community of microorganisms even though some hazardous substances may be eventually broken down in nature by natively produced communities of bacteria through mineralization and co-metabolism. Microbial degeneration was a relatively slower process that would need structural modifications. The inherent evolutionary process of microorganisms was surely unable to meet the requirements of microbial pesticides' degradation, as the speed of the process was still far from reaching what the environment and humans needed, when compared to the currently extensively utilized synthetic bio heterologous substances. As consequence, the long-term impact would be the breakdown of the ecosystem's whole equilibrium [17]. Investigating some of the strategies that could allow microbial flora to carry out optimum pesticide breakdown in a comparatively short amount of time was therefore vital and necessary.

Hintze*et al.* 2020 [82] identified that characteristics may facilitate their diffusion across surface water-groundwater interactions. They looked at how two surface water bodies from catchments with different land uses interact with an unconsolidated aquifer's spatial distribution of metabolites. Desphenyl-chloridazon (DPC) and methyl-desphenyl-chloridazon (MDPC) they're the main metabolites of the herbicide chloridized that they concentrated on, and they characterized surface water - groundwater interactions with a variety of environmental tracers (such as electrical conductivity, stable water isotopes, and wastewater tracers). Metabolite concentrations they're low in areas impacted by rivers from hilly regions (median values for DPC and MDPC they're 0.50 and 0.19 g L^{-1}, respectively). Contrarily, large concentrations they're found in places where agricultural fields they're the primary source of recharge and/or where a stream from a nearby, intensively farmed watershed had an impact (median values up to 1.9 g L^{-1} for DPC and up to 0.75 g L^{-1} for MDPC).

Gentil*et al.*2020 [83] proposed to combat pests and assure good crop yields in tropical farming systems, pesticides are widely utilized. However, the usage of pesticides also has an impact on the environment and public health. While farm management practices and environmental factors have an impact on pesticide emissions and impacts, the Life Cycle Inventory (LCI) emission models and the toxicity characterization models for Life Cycle Impact Assessment (LCIA) that are now accessible are frequently created based on temperate conditions. To evaluate pesticides in tropical environments, LCI and LCIA models must be modified. They want to discover the factors that influence pesticide emissions and associated effects in tropical environments to fill this demand. They also seek to establish how much the LCI and LCIA models should be modified to better reflect these settings. Methods They looked at the current level of knowledge on factors that influence patterns of pesticide emissions, environmental fate, ecological and human exposures, and toxicological consequences in tropical habitats.

Tao *et al.*2010 [84] assessed the effects of the impact of nonpoint-source contaminants on the sediment quality of five Kansas City streams, in Central America. Five streams with basins that extended from the city's center to its outskirts were studied in 2003, and surface sediment was collected from 29 places along those streams. 16 polycyclic aromatic hydrocarbons (PAHs), 3 typical polychlorinated biphenyl mixes (Aroclors), and 25 pesticide-related substances from eight different chemical families were all examined in the sediment. At more than 50% of the locations, several PAHs were found, and total PAH concentrations varied between 290 to 82,150 lg/kg (dry tight). With the urbanization of the residential watersheds, both the concentration and frequency of PAH detection increased. The PAH composition was predominately composed of four- and five-ring PAH compounds, especially fluoranthene and pyrene (73–100%). Table 6 shown in below.

Table 6: Review of Factors Affecting Microbial Degradation Pesticide

Citation no.	Author	year	Techniques used	Limitations/ futures scope
[76]	Yadav	2010	Degradation techniques of pesticides	While it emphasizes the need for judicious pesticide use and alternative methods, it does not delve into the practical challenges and feasibility of implementing such strategies on a large scale.
[77]	Fuentes *et al.*	2010	Dichlorination	The study did not investigate the long-term

				stability and resilience of the actinomycetes in degrading organochlorine pesticides, and further research is needed to assess their performance under different environmental conditions.
[82]	Hintze *et al*.	2020	Metabolite propagation	The study did not investigate the possible effects on health and the environment of the elevated metabolite concentrations in groundwater, which would require further research.
[83]	Gentil *et al*.	2020	Degradation techniques of pesticides	The reliance on existing knowledge and data regarding pesticide emissions and impacts under tropical conditions may be limited or incomplete. Further research is needed to enhance our understanding and improve data availability for more accurate modeling and assessment.
[84]	Tao *et al*.	2010	Sedimentation analysis technique	The need for further investigation to refine the understanding of analyzing the possible impact of environmental changes on the destiny and behavior of these chemicals. transport pathways of pesticides and PAHs from their sources to the streambed.

2.2.3. Microbial Factors

Microbial factors play a crucial role in microbial degradation processes. Different microbial species possess varying enzymatic capabilities and metabolic pathways, allowing them to degrade specific pesticides. The presence and activity of specific enzymes determine the ability of microorganisms to effectively break down pesticides. Microbes can adapt and evolve, developing enhanced degradation abilities through genetic changes. Synergistic interactions within microbial communities can enhance degradation capabilities. The biomass and growth rate of microorganisms influences the overall degradation capacity. Competitive interactions and genetic transfer can affect the effectiveness of pesticide degradation. Microbes can also adapt to specific environmental conditions, further influencing their degradation efficiency. Understanding and optimizing these microbial factors are essential for harnessing the potential of microorganisms in pesticide remediation and promoting sustainable approaches to managing pesticide residues in the environment.

Numerous studies have shown that various microbe species or strains of the same species react a different way to the same organic substrate or harmful metal, and that microorganism are very sensitive to their surroundings and can be managed. The newly discovered substances might either establish a new enzyme system to break them into smaller pieces or boost microorganisms to build their own enzyme system through the revised method. The most significant determinants were changes in degeneration and functioning characteristics [85, 86, 87, 88].

Simarro *et al*. 2013 [89] evaluated the efficacy of several in situ bioremediation treatments on creosote-polluted soil, including bioaugmentation, biostimulation, bioaugmentation plus biostimulation, and natural attenuation. The analysis includes toxicity, microbial respiration, creosote dissolution, and bacterial population growth. The outcomes showed that creosote significantly decreased in all treatments, and no significant differences between treatments were found. However, biostimulation more effectively breaks down some specific polycyclic aromatic hydrocarbons (PAH). Because of the predominance of cold temperatures (8.9 C on average), microbial absorption of creosote and PAH was hindered.

Lin*et al.*2019 [90] determined which are essential to the soil chemical cycle and ecological persistence, are put at risk by heavy metal contamination, a significant environmental problem. However, it is still unclear how various soil heavy metal pollution levels affect microorganisms and how they interact with one another. This study aims to identify damaged farms that need bioremediation and to offer helpful advice in that regard. Use species that are heavy metal resistant in diverse environmental conditions to analyze the microbial structure under varied degrees of contamination from heavy metals. In this study, the microbial populations in soils with different degrees of heavy metal contamination—severe (SL), moderate (ML), light (LL), and clean (CL)—were examined using 16s rRNA high-throughput sequencing techniques. the examination of the interactions between environmental elements and microbes.

Xun *et al.*2015 [91] examined microbial population composition and the amount of soil enzyme activity are both significant measures of soil health, it is still unclear how a soil bacterial community is established and maintained. Two samples of soil they're taken from the same area, but they were each treated to a distinct long-term fertilization strategy and had varied levels of microbial diversity, biomass, and physicochemical characteristics. These samples underwent swap inoculation and g-sterilization. Eight months of incubation they're spent incubating both unsterilized and sterilized and inoculated soil samples before they are analyzed for their nutritional content, microbial biomass, enzymatic activity, and bacterial composition.

Fu *et al.* 2022 [92] analyzed polyethylene as the most common plastic film used in agricultural production, and a major by-product of polyethylene depolymerization is polyethylene particles (PE-particles), which come in a variety of molecular weights. It is yet unclear how the molecular weights of the PE particles will affect the microenvironment of the soil and crops. Using a potted microcosmic simulation system, this study investigated how soil metabolism, microbial community structure, and crop development were affected by low, medium, and high molecular tight PE particles. Different molecular weights of PE particles have different shapes and surface microstructures. Different PE particles with different molecular weights had a big impact on how soil peroxidase and sucrase reacted. The main variables impacting the species abundance of Lysobacter they're the number of carbohydrates and amino acids present in the rhizosphere soils. Table 7 shown in below

Table 7: Review of Factors Affecting Microbial Degradation Microbial Factors

Citation no	**Author**	**year**	**Techniques used**	**Limitations/ futures scope**
[89]	Simarro *et al.*	2013	(ANOVA) The method used to evaluate the effects of treatmen	The impact of low temperatures on microbial activity and the necessity for future research to evaluate the

			t	long-term efficacy and ecological consequences of diverse in situ bioremediation approaches in varying environmental conditions.
[90]	Lin *et al.*	2019	Conventional methods.	Fungi may be essential in ecological regeneration due to their great tolerance to heavy metals. of heavy metal-contaminated systems.
[91]	Xun *et al.*	2015	Molybdenum blue method	The lack of in-depth investigation into the mechanisms connecting soil properties with bacterial community reconstruction and the need for further research to understand the long-term stability and adaptability of reconstructed microbial communities under varying environmental conditions, while accounting for the potential influence of other microorganisms, like fungi, on soil microbial dynamics.
[92]	Fu *et al.*	2022	Analyzed by one-way ANOVA using SPSS version 20.0 software	The absence of field-scale validation and the requirement for more study on the long-term effects of various PE particle weights on soil-crop interactions, microbial communities, and particular processes regulating Lysobacter species abundance in agricultural environments.

2.3. Biodiversity and Microbial Degradation

Biodiversity, referring to the variety of living organisms in a given ecosystem, plays a crucial role in microbial degradation processes. Microbial degradation, the breakdown of organic compounds by microorganisms, is influenced by the diversity and abundance of microbial species present in an environment. The relationship between biodiversity and microbial degradation has important implications for understanding and harnessing the potential of microorganisms in environmental clean-up and bioremediation efforts. Understanding the relationship between biodiversity and microbial degradation is essential for sustainable environmental management. Preserving and promoting biodiversity can enhance microbial degradation processes and improve the efficiency of bioremediation strategies. Additionally, considering biodiversity in pesticide risk assessments and management practices can help minimize negative impacts on microbial communities, safeguard ecosystem services, and foster long-term ecological sustainability.

2.3.1. Bacterial Diversity

Bacterial diversity is crucial for microbial degradation processes, allowing for the efficient breakdown of pesticides. Different bacterial species possess unique enzymatic capabilities, ensuring the degradation of a wide range of pesticides. Environmental changes select for bacteria with pesticide-degrading abilities, promoting adaptability and resilience. Bacterial diversity facilitates cooperative interactions within microbial communities, enhancing degradation capabilities. Syntropy and mutualism among bacteria enable the exchange of resources and metabolic by-products, further improving pesticide breakdown. Understanding and harnessing bacterial diversity can lead to effective strategies for pesticide remediation and environmental protection.

Talia*et al.*2012 [93] assessed the rhizosphere, a dynamic interface, the interactions among several microbes affect how well plants tolerate stress and flourish. Although the impacts of the rhizosphere on soil microbial communities have been extensively investigated, little study has looked at the consequences of continual fertilization on the rhizosphere microbial populations in northeast China's distinctive black soils. Here, they used a long-term (36-year) fertilizer experiment to characterize the rhizosphere and bulk soil bacterial communities using high-throughput pyrosequencing and quantitative real-time polymerase chain reaction. The six different soil treatments used are CK (no fertilizer), N_1 (150 kg of urea per hectare per year), N_2 (300 kg per hectare per year), M (18,600 kg of horse manure per year), and NPK (150 kg of nitrogen per hectare per year).

Zeng*et al.*2016 [94] determined how nitrogen (N) deposition affects above- and below- ground populations as well as the functioning of an ecosystem. However, it is uncertain whether nitrogen deposition affects soil, plant, or microbial interactions directly or indirectly. This study looks at how the variety of soil bacteria responds to N enrichment at the soil's surface (0–10 cm) and beneath (10–20 cm). Even at the greatest addition rate (240 kg N ha1 yr^{-1}), the surface soil saw a significant shift in the makeup of the bacterial community and a decrease in the richness of bacterial OTUs as a result of addition (>120 kg N ha1 y^{r-1}). There were substantial correlations between bacterial OTU richness and soil and plant properties. According to hierarchical structural equation modeling, changes in the availability of the soil's ammonium caused changes in bacterial richness, whereas changes in the composition of the plants affected the composition of the bacterial community.

Wang*et al.*2018 [95] assessedthat even though rhizosphere impacts on soil microbial communities have been extensively researched, this study looked at how long-term fertilization affected the microbial populations in the rhizosphere of the black soils typical of northeast China. Here, quantitative real-time polymerase chain reaction and high-throughput pyrosequencing were used in a long-term (36-year) fertilizer experiment to characterize the rhizosphere and bulk soil bacterial populations. Six soil treatments are used: CK (no fertilizer), N_1 (150 kg of urea per hectare per year), N_2 (300 kg per hectare per year), M (18,600 kg of horse manure per year), and NPK (150 kg of urea + 33 kilograms of P plus 62 kilograms of K per year). Table 8 Shown in below.

Table 8: Review of Biodiversity and Microbial Degradation Bacterial Diversity

Citation no.	**Author**	**year**	**Techniques used**	**Limitations/ futures scope**
[93]	Talia *et al.*	2012	1. DNA extraction 2.Rarefaction curves	Comparative analysis of ribosomal RNA genes reveals the diversity and abundance of cellulolytic bacteria in native Chaco soil, providing valuable insights into their ecological role and potential for biodegradation
[94]	Zeng	20	Phyloge	The bacterial

	et al.	16	netic analysis	population in the soil is anticipated to be impacted by changes in soil organic matter amount and quality.
[95]	Wang *et al.*	2018	one-way ANOVA	Insufficient bacterial taxonomic and functional characterization and the need for additional experiments highlight the necessity for further research on the functional consequences of rhizosphere microbiome changes caused by heavy fertilizer use in agricultural ecosystems.

2.3.2. Fungal Diversity

Fungi, with their diverse species and enzymatic capabilities, are vital for microbial degradation and overall biodiversity. They decompose organic materials, contributing to nutrient cycling and ecosystem functioning. Fungal diversity ensures efficient decomposition and recycling, releasing essential nutrients. Fungi also form symbiotic relationships with plants, enhancing plant growth and ecosystem productivity. However, habitat destruction, pollution, climate change, and invasive species pose threats to fungal diversity. Loss of fungal diversity disrupts ecosystem processes, hampers nutrient cycling, and impacts ecosystem stability. Safeguarding fungal diversity is crucial for maintaining healthy ecosystems and sustainable agriculture.

Arenz*et al.*2014 [96] assessed the first records of fungi that have been found in Antarctica since the early 20th century, and they originate from a wide range of soils and substrates in various ecosystems and environments. The non-lichenized fungus has frequently been studied separately from lichenized forms in Antarctic investigations, and more than 1,000 different species of the discovery of non-lichenized fungi from locations across Antarctica, including the sub-Antarctic. Given that fungi are notorious polluters, especially in areas where humans gather, it's critical to recognize the difficulties in discerning between invasive and transient mushrooms and locally endemic species and comprehend their various contributions to terrestrial biodiversity.

Hoppe*et al.* 2016 [97] analyzed that fungi have supported Antarctica's ecosystems for 200 million years and have been there at least since the Triassic Period. The earliest reports of fungi in Antarctica date back to the early 20th century, and they originated from a wide range of soils and substrates that were found in various climatic and geographic settings.Non-lichenized fungi have frequently been studied apart from lichenized forms in Antarctic investigations, and more than 1,000 species of non-lichenized fungi have been identified from Antarctic locales, including the sub-Antarctic. Since fungi are notorious pollutants, particularly in locations where people interact with the environment, it is crucial to understand the difficulties in identifying between transient/introduced, native, and endemic fungi as well as their contributions to terrestrial biodiversity.

Yuan*et al.*2013 [98] examined the objective of the soil's biological qualities and relevant soil ecological processes that may be impacted by long-term fertilization, which might influence sustainable agriculture. Effects of chemical fertilizers (NPK), no fertilizer (CK), and NPK coupled with rice straw residues (NPKS) over a lengthy period (>25 years), as they'll as changes in soil quality, they're investigated in this study. Resources and techniques Mid-summer to early fall of 2009 saw the collection of soil samples from a long-term field site in subtropical China's Wang Cheng County, which had been established in 1981. To analyze the bacterial and fungal community as well as the microbial biomass (MB-C, -N, and -P), terminal restriction fragment length polymorphism (T-RFLP), and real-time quantitative polymerase chain reaction (real-time qPCR) they're used.

Seena, *et al* 2019 [99] composed groundwater habitats that make up the majority of the largest terrestrial freshwater biome. However, although freshwater habitats are hubs for biogeochemical cycles and biodiversity, large-scale patterns of microbial diversity in these aquatic environments remain a little unexplored. This article reports the findings of a thorough investigation using Illumina sequencing to examine the variety of leaf-litter fungi in streams over a latitudinal gradient. The study is based on observations of fungal communities colonizing standardized plant litter at 19 widely separated stream locations between 69°N and 44°S. The quantity of fungi implies a latitudinal gradient with a hump-shaped distribution. Surprisingly, temperature preferences had a more significant impact on the composition of mushroom communities than did biogeography. Table 9 Shown in below.

Table 9: Review of Biodiversity and Microbial Degradation Fungal Diversity

Citation no.	**Author**	**year**	**Techniques used**	**Limitations/futures scope**
[96]	Arenz *et al.*	2014	Identification and detection method	The challenging and harsh environmental conditions in Antarctica can restrict sampling and data collection, as well as the limited accessibility to Antarctic soils, which may limit the representation and generalizability of the findings to broader Antarctic regions.
[97]	Hoppe *et al.*	2016	To connect WIF richness, taxonomic identity, and specified cumulative OTU with microbial-mediated enzyme activity	Due to the selective colonization of certain fungi on deadwood and the difficulties in precisely relating particular ecological services and activities in complex forest environments, fungus diversity, and community dynamics, there may be sampling biases.
[98]	Yuan *et al.*	2013	T-RFLP analyses	Potential confounding factors from other soil parameters may influence microbial biomass and community structures, and challenges in determining the causal relationships between long-term fertilization and observed microbial responses due to the complex interactions in soil ecosystems.
[99]	Seena *et al.*	2019	linear regression models	The potential confounding factors from other environmental variables

				along the latitudinal gradient may influence fungal biodiversity and challenges in accurately identifying and quantifying fungal species in leaf litter samples from streams.

2.3.3. Protozoan Diversity

Protozoan diversity refers to the wide range of species and genetic variation found within the group of single-celled eukaryotic microorganisms known as protozoa. Protozoa are incredibly diverse, both in terms of their morphology (physical structure) and their ecological roles. They inhabit a variety of habitats, including freshwater, marine environments, soil, and the intestines of other organisms. Protozoa exhibit incredible diversity in their ecological roles. In nutrient cycling, they perform crucial functions, energy transfer, and food chains. Some protozoa are primary producers, using photosynthesis to produce organic matter, while others are consumers, feeding on bacteria, algae, or other protozoa. Protozoa are also important predators, regulating the populations of bacteria and other microorganisms.

Tocch *et al.*2012 [100] examined the performance efficacy of various aeration regimes was evaluated, as well as any connections to the communities of bacteria and protozoa in the activated sludge in a three-reactor industrial facility that treats 45 m3 of dairy effluent per day. When the plant was operating at six different "on/off" cycles (45/15, 15/15, 15/45, 30/30, 45/45, and 30/60 min), the important chemical and biological parameters (COD, BOD, NH4, NO2, NO3, PO3, etc.) were measured. The COD elimination efficiencies were constantly between 88 and 94% when at least 45.4 kg of oxygen per day (30/45) was provided, but under the aeration regimes of 15–45 and 30–60, they decreased to about 70%. The only effect of ammonium ion decomposition in the most recent aeration regime (15/45) was impaired. Protozoa and bacteria's cell abundances and community architectures varied with the aeration regimes but remained remarkably comparable in all three aerated reactors.

Ferris and Tuomisto 2015 [101] assessed the soil offers a wide range of microhabitats for a wide range of species with diverse sizes, physiological functions, behaviors, and ecosystem activities. In addition to the large number of participating soil organisms, the species variety of these organisms enables the best possible use of the resources present in the various environments. The diversity of guilds within a functional class expands the range of settings in which ecosystem services are provided, whereas species diversity within a functional class and its guilds increases the overall quantity of services. Consequently, a key aspect of the biological component of soil health is the variety of species within functional categories. A species' biomass or metabolic activity is a more relevant indicator of its abundance than its population size in terms of ecosystem services and soil health.

Pathma and Sakthivel 2012 [102] assessed the earthworms and associated microorganisms that are used in the oxidative, non-thermophilic process known as vermicomposting. The vermicompost, a biofertilizer, is produced by the biological decomposition of organic waste. Vermicompost is a finely split, peat-like substance that is very porous and has great nutritional status, a good drainage system, water-holding capacity, microbial activity, and buffering ability. These factors all work together to produce the necessary physiochemical characteristics beneficial to soil fertility and plant growth. Vermicompost increases by promoting beneficial bacteria in the soil, soil biodiversity is increased. Beneficial microbes in turn support plant development both directly by creating hormones and enzymes that control plant development as well as indirectly by preventing the spread of pests, nematodes, and other plant diseases. This increases the health of the plant and lowers yield loss.

Griebler *et al.* 2014 [103] composed the biggest terrestrial freshwater biome is one which is primarily composed of groundwater habitats. Despite being dark, very energy-poor, and small, they contain an incredibly wide variety of living things, many of which have recognizable adaptive traits. Testing scientific ideas and deciphering ecosystem functioning has been difficult for a very long time because of the limited accessibility and vast "invisible" variety. Groundwater ecology gains speed as it enters a new area of research, spurred by enhanced interdisciplinarity, extensive sampling methodologies, and contemporary breakthroughs in biotechnology and statistical analysis.

Papale*et al.*2019 [104] investigated they were found under an ice-sealed Antarctic Lake and were identified as two discrete TF_4 and TF_5, which are separated by a thin ice barrier, are pressurized hypersaline brine pockets. An integrated strategy including both conventional and cutting-edge techniques was used to investigate the metabolic characteristics of prokaryotic (bacterial and archaeal) organisms. In the shallowest brine pocket, TF_4, Bacteroidetes, and Gammaproteobacterial they're more prevalent, while in the deepest brine pocket, TF5, Deltaproteobacteria, mostly represented by adaptable sulfate-reducing bacteria, predominated. The discovery of methanogenic Archaea and sulfate-reducing bacteria in TF_5 likely indicates the presence of a unique syntrophic consortium. In line with the observed microbiological variety between TF_4 and TF_5 brines the patterns of microbial communities they're different.

Usharani et al.2019 [105] researched the term "soil health" which describes the ecological balance, functioning, and ability of soil to sustain a healthy ecosystem with high biodiversity and production. Physical, chemical, and biological characteristics of soil health as a tool for sustainability. Commonly utilized physical indicators include soil texture, aggregation, moisture content, porosity, and bulk density. As well as biological indicators like microbial biomass C and N, biodiversity, soil enzymes, soil respiration, etc., as well as macro and meiofauna, chemical indicators like soil pH, total C and N, organic matter, and cation exchange capacity play a crucial role in maintaining soil health. Table 10 Shown in below.

Table 10: Review of Biodiversity and Microbial Degradation Protozoan Diversity

Citation no.	**Author**	**year**	**Techniques used**	**Limitations /futures scope**
[100]	Tocchi *et al.*	2012	Most probable number (MPN) count technique	The potential for variations in reactor performance and microbial community dynamics due to operational factors and the challenges of accurately characterizing and monitoring protozoan and bacterial communities in complex wastewater treatment systems.
[101]	Ferris *et al.*	2015	Bioremediation mechanism	The complexity of assessing and quantifying soil biological diversity and the difficulty in establishing causal links between diversity and the state of the soil.
[102]	Pathma *et al.*	2012	1)General suppression 2)Specific suppression	Environmental factors can also impact microbial composition and function, affecting the

				interpretation and generalization of findings.
[103]	Griebler*et al*.	2014	Bioremediation techniques	Due to the site-specific character of groundwater ecosystems and their diverse hydrogeological circumstances, generalizing results from particular groundwater systems to a larger scale can be difficult.
[104]	Papale *et al.*	2019	Degradation techniques of pesticides	Seasonal fluctuations may affect seasonal changes in microbial assemblage diversity and activity, which were not fully addressed in the research.
[105]	Usharani *et al.*	2019	Infiltration	The development of standardized, broadly applicable evaluation techniques is hampered by the difficulty of conducting a full assessment of soil health.

3.APPLICATIONS OF MICROBIAL DEGRADATION OF PESTICIDES IN AGRICULTURAL ENVIRONMENTS

Pesticide Remediation: Microbial degradation offers a promising remedy for cleaning up soils and water bodies poisoned by pesticides. By harnessing the natural abilities of microorganisms to degrade pesticides, microbial bioremediation techniques can be employed to reduce pesticide residues and restore contaminated environments.

Sustainable Agriculture: Understanding and harnessing microbial degradation processes can contribute to the development of sustainable agricultural practices. By promoting the use of microbial bioremediation, farmers can minimize the environmental impact of pesticide use and lessen the buildup of pesticide residues in the soil and water, thereby promoting ecologically friendly and sustainable farming practices.

Integrated Pest Management (IPM): Microbial degradation plays a vital role in integrated pest management strategies. By incorporating microbial bioremediation as a component of IPM, farmers can reduce their reliance on chemical pesticides and adopt a more holistic approach to pest control, integrating biological, cultural, and chemical control methods.

Soil Health and Nutrient Cycling: Microbial degradation of pesticides can contribute to the overall health and functionality of agricultural soils. By promoting the activity of pesticide-degrading microorganisms, soil microbial communities can be enhanced, leading to improved nutrient cycling, organic matter decomposition, and overall soil fertility.

Environmental Protection: The application of microbial degradation in pesticide management can help protect the environment by reducing the accumulation of toxic pesticide residues in ecosystems. By enhancing the natural breakdown of pesticides, the risk of pesticide runoff, leaching into groundwater, and contamination of surface water can be minimized, protecting aquatic ecosystems and non-target organisms.

Ecological Balance and Biodiversity Conservation: Microbial degradation of pesticides can help maintain ecological balance and preserve biodiversity. By promoting the degradation of pesticides, the potential negative effects of these chemicals on non-target organisms, including beneficial insects, birds, and soil organisms, can be reduced, contributing to the conservation of biodiversity in agricultural environments.

Human Health and Food Safety: Effective microbial degradation of pesticides can contribute to improving food safety and reducing human exposure to pesticide residues. By employing microbial bioremediation strategies, the levels of pesticide residues in crops and agricultural products can be minimized, ensuring safer food for consumption.

Sustainable Development Goals (SDGs): The application of microbial degradation aligns with several United Nations Sustainable Development Goals, including Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-being), Goal 12 (Responsible Consumption and Production), and Goal 15 (Life on Land). By promoting sustainable agricultural practices and reducing the environmental impact of pesticides, microbial degradation contributes to achieving these global sustainability goals.

4. Discussion

To manage pests and weeds, agriculture must employ pesticides and herbicides, but doing so has dangers for the environment and human health. Microbes offer a promising solution for degrading these chemicals and reducing their negative impact. This literature review aimed to identify the specific microbes involved in degrading agricultural chemicals and evaluate their effectiveness. Through a systematic review of relevant studies, factors influencing microbial degradation efficiency were identified, including microbial community composition, environmental conditions, pesticide properties, microbial adaptation, synergistic interactions within microbial consortia, and genetic transfer. The review also highlighted research gaps, such as the need for further understanding of microbial adaptation mechanisms and the long-term effects of pesticide exposure on microbial communities. By optimizing microbial degradation processes and considering these factors, sustainable and eco-friendly approaches can be developed to address pesticide residues in agriculture.

5. Conclusion

The microbial species that exist in the environment, studies conducted on bacteria that are capable of dissolving down herbicides and pesticides, and the approach and application of these bacteria have all been discussed in the paper. A large portion of the microbial strains that deplete pesticides have been noticed, and microbial degradation research on pesticides has grown significantly. However, the real-world use of microbial bioremediation has been constrained, largely due to the environment and the low degradable efficiency of the procedure. In conclusion, microbes have shown promise in degrading agricultural environmental hazards, such as pesticides and herbicides, offering a sustainable solution to mitigate their negative impact. Factors such as microbial community composition, environmental conditions, pesticide properties, and interactions with other chemicals play significant roles in microbial degradation efficiency. The formation of high efficiency pesticide degradation engineering bacteria, cultivation of mixed bacteria, the fixation of degrading bacteria, the study of pesticide-degrading fungi, and a quantitative assessment of pesticide biodegradation designs were the primary investigation directions for the microbial degradation of pesticides. Microbial adaptation, synergistic interactions within consortia, and genetic transfer were identified as important mechanisms for enhancing pesticide degradation. The study highlights the need for further research to fill gaps in the current knowledge and suggests that optimizing microbial degradation processes can lead to sustainable and eco-friendly approaches for addressing pesticide residues in agricultural environments. Overall, microbial consortia have great potential as a viable strategy for pesticide remediation.

6. Future Persepectives

A large portion of the microbial strains that destroy pesticides have been determined, and microbial degradation studies on pesticides have advanced drastically. On the other hand, the actual use of microbial bioremediation remains restricted, largely because of the environment and the low degradable efficiency of the procedure itself. The key problems that need to be rectified before microbial pesticides are widely used are their specificity and lack of performance against a variety of pests. Whereas specificity is regarded as a benefit, in contrast to synthetics, it also restricts the market and raises payments. The reactivity of bio-pesticide preparations to heat, desiccation, and UV radiation, which reduces their effectiveness, is another important consideration. It becomes essential to use particular ingredients and storage circumstances, which can make product distribution and application challenging. The application of genetic engineering and molecular genetics to the study of microorganisms will aid in the creation of new strategies for enhancing the effectiveness and application of bio-pesticides. More investigation needs to be conducted to improve the bio-pesticides' field effectiveness, speed of kill, biological spectrum, and duration of storage. In order to effectively progress the field of microbial degradation of pesticides and to overcome the obstacles experienced throughout the process, more studies should be conducted and innovative techniques should be examined.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.