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THE ROLE OF *PSEUDOMONAS* BACTERIA IN THE BIOREMEDIATION OF PESTICIDE-CONTAMINATED ENVIRONMENTS: A LITERATURE REVIEW

Abstract: *Currently, the spread of pesticides in the agro-industrial complex poses a serious threat to the stability of ecosystems, soil quality and human health. In this regard, there is growing interest in biological recovery technologies as an effective way to address this global environmental challenge. In this direction, the bacteria of the genus Pseudomonas attract special scientific attention, possessing high metabolic activity and the ability to break down synthetic chemicals. This literature review provides a bibliometrical and content analysis of the latest scientific research on the role of Pseudomonas bacteria in the bio-recovery of environments contaminated with pesticides. According to research, the number of scientific publications on this topic has been growing steadily in recent years. India and China stand out as countries that are actively pursuing research in this direction. Most scientific work is concentrated in the fields of ecology, microbiology and biochemistry. As part of this study, using the Prisma methodology, a selection of scientific publications from the Scopus database was made for the period 2010-2026. The search for articles in the Scopus database was carried out using keywords «pesticide stress» and «pseudomonas». The results of the search by keywords selected 91 articles, and in the selection were considered 20 most significant. Only referenced articles published in English were included in the analysis. Studies show that Pseudomonas bacteria are actively involved in pesticide degradation, reducing oxidative stress and restoring contaminated soil microflora. Pseudomonas bacteria have been widely studied in terms of nitrogen fixation, the release of axins, plant growth stimulation by formation of phytohormones, destruction of phyto-pathogens, and the production of antibiotics. Although the effects of bacteria on abiotic stress (drought, salination) are often discussed, data on their ability to relieve pesticide stress is still missing. Their use to clean up soil and aquatic ecosystems contaminated by pesticides is one of the effective strategies for sustainable environmental management.*

Key words: *Pseudomonas bacteria, abiotic stress, pesticide, bio-medicine, VOSviewer, Bibliometrix.*

Introduction

Pesticides are used in agriculture to protect plants from pests, infectious diseases and weeds. However, their overuse pollutes the soil and the ecosystem around plant roots. This affects the life and function of natural microorganisms. Pesticides and other toxic substances remain in the soil for a long time, causing stress to plants. They alter plant metabolism, enzymatic activity and the structure of cell membranes. Environmentally friendly cleaning of pesticide-contaminated environments is a pressing issue. Therefore, bioremediation is an important area. The use of bacteria to enrich plants with minerals and increase their resistance to abiotic stress is one effective method.

Recent studies show that microorganisms have a high capacity to adapt to adverse conditions. This allows them to be used as an effective means of cleaning up pollution. For example, it has been found that the use of bacteria of the genus *Pseudomonas, Bacillus, Azotobacter* reduces conditions of abiotic stress. Microorganisms can regulate plant growth and their protective mechanisms. This is also important in conditions of pesticide contamination. Bacteria of the genus *Pseudomonas* arouse particular interest in biorecovery due to their high metabolic flexibility, active growth in the root zone and ability to adapt to toxic substances.

Modern biotechnology is opening up new opportunities to improve the microbes that can break down pollutants. This is especially true for bacteria of the genus *Pseudomonas*, as their genomic and metabolic flexibility allows them to reinforce specific degradation pathways, increase resistance

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to pesticides, and enhance the efficiency of bio-recovery. However, the application of these technologies raises issues such as environmental safety, genetic stability and efficacy under specific conditions.

Studies show that the ability of microorganisms to adapt to stress, interact with plants, exhibit resistance to biocides, and decontaminate is the scientific basis of biorecovery. In this context, bacteria of the genus *Pseudomonas* are considered as promising biological agents for restoring environments contaminated by pesticides. Their high catabolic activity, diverse enzyme systems, ability to withstand pesticide stress, and adaptation in the radiosphere make these bacteria an important research object in environmental biotechnology.

The aim of this literature review is to analyze the role of *Pseudomonas* bacteria in the bio-medicine of environments contaminated with pesticides, based on modern scientific literature. The article discusses mechanisms of adaptation of microorganisms to pesticide stress, the link between resistance to biocides and detoxification, the ecological significance of microbial inoculation, as well as the possibilities and limitations of the use of *Pseudomonas* bacteria in biomedical technologies. Such an analysis will serve as a theoretical basis for developing environmentally sound, efficient and sustainable biotechnological techniques aimed at reducing pesticide pollution. To this end, the following research questions have been raised in the context of Bibliometric analysis:

What scientific research is available on the bio-therapeutic potential of *Pseudomonas* bacteria in environments contaminated with pesticides?

How do micro-organisms adapt at the physiological and biochemical levels to pesticide stress?

What is the capacity of *Pseudomonas* bacteria to degrade pesticides and the environmental significance of bioremediation?

To answer these questions, a literature review was conducted on articles published in the scientific databases *Scopus, Google Scholar* and *ResearchGate* for the period from 2010 to 2026. The articles collected were selected using *PRISMA* methodology. The ability of *Pseudomonas* bacteria to break down, their adaptation to adverse conditions and their application in biotechnology were considered.

Biohealth of polluted environments is one of the important areas of modern environmental biotechnology. The use of *Pseudomonas* bacteria in this process not only accelerates the degradation of toxic substances in the environment, but also contributes to restoring ecosystem resilience by maintaining a microbial balance. The high metabolic flexibility and resistance of these bacteria to xenobiotics make them promising biological cleaners in bio-recovery technologies. Therefore, scientific substantiation of the role of *Pseudomonas* bacteria in the bio-recovery of pesticide-contaminated environments and their ecological potential is an urgent scientific task.

Environmental challenges of pesticide pollution

In agriculture, pesticides are widely used to increase crop yields and control pests. However, their negative environmental impact is a serious problem. The accumulation of pesticides in soil, water, and air poses a significant threat to ecosystem balance, biodiversity, and human health.

Studies in environmental science have shown that pesticides are ubiquitous and contaminate soil composition. According to research by H. M. Tan and her colleagues, 64% of the world's agricultural land is subject to pesticide contamination. Pesticide residues exceeded permissible levels by approximately 24.5 million square kilometres of agricultural land. Researchers have studied biodiversity disruption and pollution of watersheds in regions of South Africa, China, India, Australia, and Argentina [1].

The study of scientists under D.D. Snow, devoted to the river Syrdarya, revealed the presence of residues of both modern and previously used pesticides in water systems of Kazakhstan. The authors found high concentrations of organochlorine pesticides such as gamma-HCH (lindane), DDE and dieldrin. Particularly high levels of gamma-HCH, in the range of 0.014-0.24 ug/l, have been estimated to be among the highest among rivers worldwide. According to scientists, these pollutants pose a long-term environmental threat to aquatic organisms. The source of pollution can be both past illegal uses and historical pollution spread through melting ice [2].

Research by Anirudha Sarker and his colleagues has explored the pesticide content in soil more deeply. According to their data, only about 5% of the pesticides used have effective effects on pests. The rest accumulate in soil or become toxic substances. In particular, organochlorine pesticides degrade very slowly and therefore persist for a long time as persistent organic pollutants. For example, dichlorodiphenyl dichloride and its decay products remain in soil and water systems for decades even after prohibition, indicating the complexity of the environmental problem [3].

The airborne distribution of pesticides is also a serious problem. According to researchers led by Tirasant Bunupar, around 2.6 million tons of active pesticides are used worldwide each year, with a significant proportion of these going into the atmosphere. Studies have shown that between 30 and 50% of pesticides are released into the air when sprayed. This occurs through processes of dispersion in the air and evaporation. Scientists have found that pesticides, spreading over long distances in the air, contaminate not only water and soil, but also the atmosphere. In addition, pesticides in the air can be in a gaseous, liquid, and solid state, posing a risk to human health [4].

The importance of bioremediation in modern biotechnology

Today, bio-medicine is recognized as a worthy alternative to traditional physico-chemical methods of environmental cleaning. Traditional methods, such as incineration, chemical treatment and landfill on polygons, are further damaging to the environment and costly. Biological recovery, by using the natural processes of living organisms, especially micro-organisms, enables ecosystem restoration to be cost-effective, safe, and long-term. The importance of bioremediation is determined by:

– Environmental cleanliness: This method prevents the accumulation of harmful substances in the environment and safely destroys them.

– Economic advantage: Studies show that bio-health care reduces costs by 65-85% compared to traditional methods.

– Applicability: Biomedicine can clean up various pollutants, from heavy metals to petroleum products and other complex organic pollutants.

The bioremedial potential of Pseudomonas bacteria

Pseudomonas bacteria contribute significantly to clean contaminated soils and water systems. Doolotkelvieva and his colleagues (2015) , Giri and his colleagues (2020) have investigated whether they are related to their metabolic predisposition and unusual catabolic ability to cleave xenobiotics [5-6]. Dhakal and his colleagues (2025) stated that microorganisms can break down the chemical structure of pesticides through enzymatic processes such as oxidation, hydrolysis, and nitridation, turning them into harmless compounds [7]. The pesticide cleavage process is often regulated by plasmid genes and horizontal gene exchange mechanisms, which enhance their resilience to environmental conditions. In addition, *Pseudomonas* strains enhance detoxification processes by activating antioxidant systems in the soil, contributing to restoration of damaged ecological balance [8-9]. Looking at the study by Varghese and his colleagues (2025), this metabolic diversity of microorganisms allows them to use pesticides as a source of carbon and energy [10]. This makes them a sustainable and cost-effective method of bio-recovery. It protects plants from adverse conditions such as salinity and drought. For example, in soil contaminated by salt cadmium (Cd). koreensis and P. when using PGPR bacteria such as stutzeri, the cadmium content in plant grains decreased by 50% and yields increased by 25%.

Methods

The article review focuses on the role of bacteria of the genus *Pseudomonas* in the biorecovery of pesticide-contaminated environments. The study only considered peer-reviewed publications from Scopus, ResearchGate and Google Scholar databases. The data collection was based on predefined search parameters. The selection of articles was made according to the PRISMA structure for the period from 2010 to 2026. The following search algorithm was used:

TITLE-ABS-KEY pesticides stress AND pseudomonas) AND PUBYEAR > 2009 AND PUBYEAR < 2027 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (EXACTKEYWORD, "Pseudomonas Putida") OR LIMIT-TO (EXACTKEYWORD, "Pesticide") OR LIMIT-TO (EXACTKEYWORD, "Plant Growth") OR LIMIT-TO (EXACTKEYWORD, "Bioremediation") OR LIMIT-TO (EXACTKEYWORD, "Abiotic Stress") OR LIMIT-TO (EXACTKEYWORD, "Pseudomonas Aeruginosa") OR LIMIT-TO (EXACTKEYWORD, "Pseudomonas Fluorescens") OR LIMIT-TO (EXACTKEYWORD, "Pseudomonas")).

This section discusses the biometric aspects of the study and defines the role of *Pseudomonas* bacteria in the bioremedicine of pesticide-contaminated environments. Then there was a content analysis of the identified studies with a systematic examination of their conceptual foundations, methods of study and main conclusions. This two-stage analysis provides a complete overview of the topic. The selection of articles was made according to the PRISMA structure for the period from 2010 to 2026. The main keywords used were *"pesticides stress"* and *"pseudomonas"*. An analysis of the development of the research area from 2010 to 2026 (see Figure 1) shows an increase in activity. Between 2010 and 2016, an average of 1-3 articles per year were published,

which indicates the stage of methodological development of the topic. Since 2017, there has been an increase in the number of articles indicating the beginning of the application of the method of bioremediation. The period from 2017 to 2020 is a period of growth of the topic, with 4-6 articles per year, and the number of links has increased significantly. Maximum performance was achieved in 2021-2022. The exponential period of the theme covers 2021-2025. There were 200 links in 2021, 300 in 2022,380 in 2023, 540 in 2024, and 600 in 2025. Statistics show that the topic has been very topical in recent years. As a modern global issue, papers on bio-health, environmental protection and climate have high penetration rates in Scopus and WoS. In addition, international links increase the number of citations of publications. As a result, there is growing demand for microorganism biomedicine and the use of biologically safe drugs instead of pesticides. The relevance of research grows with each passing year. The application of bio-health care is important not only in agribusiness, but also in agroeconomics, health care and environmental protection.

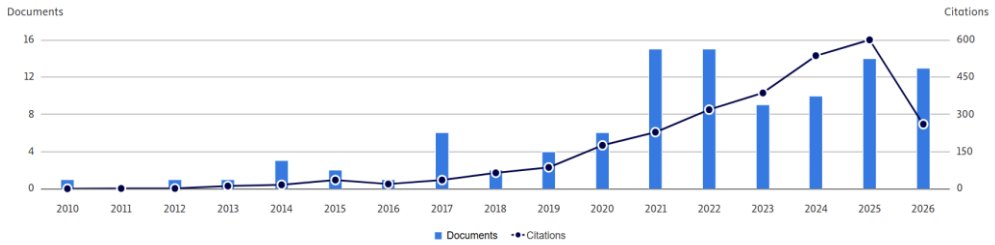


Figure 1 – Dynamics of scientific publications

Figure 2 provides a literature review on the PRISMA methodology. The review covered publications from 2010 to 2026. Articles on the use of *Pseudomonas* bacteria for bioremediation of pesticide-contaminated media were considered. Initially, a total of 173 publications were found as a result of searches in databases and review articles. The keywords "pesticide stress" and "*pseudomonas*" were used. The use of automated filters resulted in the deletion of 61 articles. As a result, 91 studies were selected for further study.

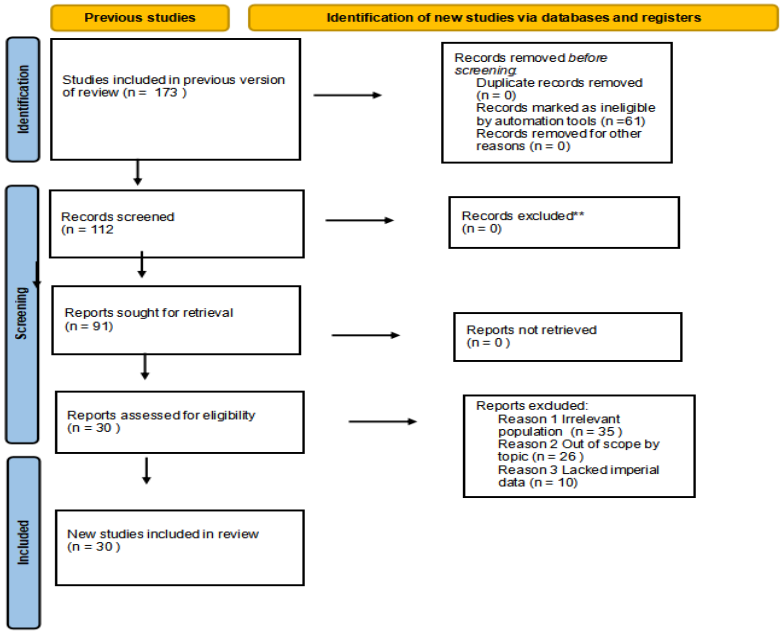


Figure 2 – Diagram of research analysis according to the PRISMA methodology

During the reading of the article annotations, 61 studies were unrelated to the topic. Thus, 30 articles relevant to the topic were selected using this methodology. The PRISMA analysis enhanced the accuracy and credibility of our review.

Results and discussions

Figure 3 shows the distribution of scientific publications by country. The scale of the chart shows that this topic has become a global environmental issue. India leads with approximately 27 publications, highlighting the high relevance of active research in pesticide contamination and bio-medicine in the country. China ranks second with nearly 24 publications, also actively promoting microbiological research aimed at reducing the environmental impact of agricultural chemicals. Rapid industrial development and intensive agriculture in both countries have resulted in the contamination of soil and water with pesticides, heavy metals such as the Ganges, China's industrial areas, and other harmful substances. This question is relevant. About 11 papers with the same number of publications in Egypt and the US. Pakistan and Saudi Arabia show moderate activity with 8-9 articles. Research in Brazil, Iran, Germany, and Italy is relatively scarce. Research in these countries will likely focus on other areas of CRISPR technology or traditional bioremediation methods rather than bioremediation. For example, improving crops, making them more resilient. In countries that strictly control the products of genetic engineering, research is slow.

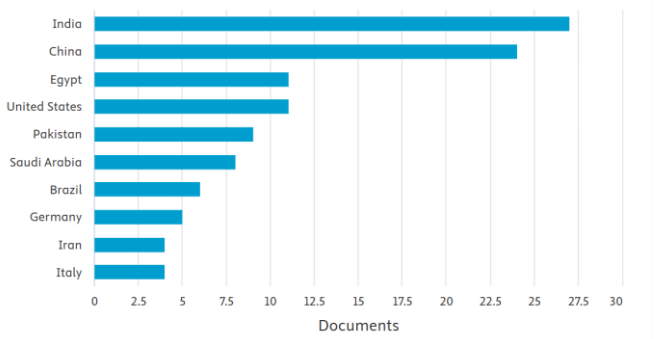


Figure 3 – Distribution of scientific publications by country

The results of the analysis of the diagram show the geographical spread of studies aimed at using the bacterium *Pseudomonas* for environmental bio-medicine contaminated by pesticides. According to statistics, India, China, and Egypt are leaders in the study of pesticide contamination. These countries are experiencing environmental crises due to severe pesticide contamination of soil and water. In India, for example, the widespread use of pesticides often reveals residues of banned compounds from vegetables and soil. In China, high concentrations of obsolete organochlorine pesticides have been found in agricultural areas. Scientists in these countries are actively studying the natural decomposition of *Pseudomonas* bacteria to clean up contaminated environments.

In India, strains of *Pseudomonas putida* and *Pseudomonas fluorescens* have been shown to use organochlorine pesticides as well as organophosphorous compounds as a carbon source. However, some commercial pesticide residue-removal biodrugs are made from the enzymes of these bacteria.

Pseudomonas spp in China. assessment of pesticide distribution and methods of their bio-recovery are intensively studied. In particular, the effectiveness of cleaning pesticide residues in agricultural soils with a strain of *Pseudomonas* is tested.

Along with phytoremediation, Egypt is studying the restoration of contaminated land by introducing into the soil *Pseudomonas* bacteria, which break down pesticides.

In developed European countries such as Germany and Italy, pesticide use is strictly controlled. Therefore, the level of soil contamination is relatively low. Scientific funding is directed toward the development of biological pest control or plant resilience, rather than to bio-recovery. One of the predominant environmental problems in Iran is water scarcity and desertification, so it has been observed that studies have been more focused on resistance to salinity and drought than on pesticides. Figure 4 shows the main areas of industry for microorganism biorecovery. The leading role on this topic is played by environmental articles, the percentage is 17.9%.

This is because bio-health is directly related to nature conservation. The research focuses on cleaning water from soil degradation using bioremediation. In second place - biochemistry and molecular biology with 16.1%. In this direction, the ability of bacteria to cleave pesticides is being investigated. Analyses of bacterial enzymes, genetic features, and processes of metabolism. The

next parts of the share are: microbiology 14.3%, medicine 11.2%, agriculture 10.3%, chemical engineering 8.1%, pharmacology 4.9%. Research has highlighted important areas of cleaning up pesticide-contaminated environments using *Pseudomonas* bacteria. Much of the research is focused on ecology, biochemistry, and microbiology. This shows that bio-medicine has high biotechnological potential for environmental cleaning. Studies not only environmental protection, but also the effects of pesticides on human health. The importance of their biological sterilization is addressed in medical research.

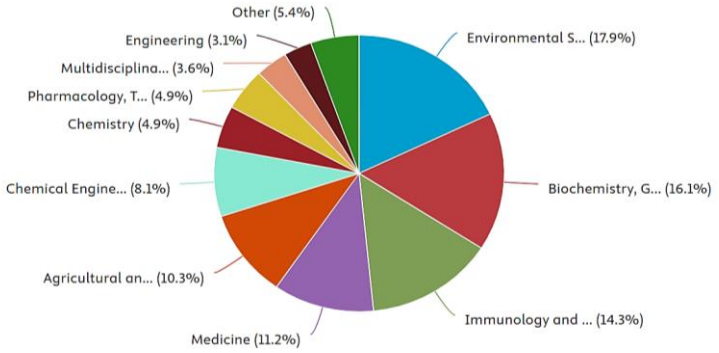


Figure 4 – Directions of research by scientific fields

It is important to understand more deeply how and which genes bacteria cleave pesticides. For example, the bacterium *Pseudomonas* putida can break down malathion and chlorpyrifos up to 98%. The results of these studies are published in traditional scientific journals such as biology, chemistry and toxicology. Research that combines engineering systems, artificial intelligence, and biology is a relatively new field. Such interdisciplinary research requires close collaboration among professionals from different sectors. However, there are a small number of scientists with deep knowledge in biology, chemistry, computer science and engineering, which increases the complexity and cost of such projects.

Engineering aspects of bioremediation, in particular the introduction of genetically modified micro-organisms into natural ecosystems, pose safety and regulatory challenges. So far, no genetically modified micro-organism has been used commercially. In addition, there are still serious technological barriers to adapting the laboratory's achievements to specific field conditions.

Figure 5 presents the most active authors who have studied the use of bacteria in pesticide deposition. Brazilian scientist Pleggi who has thoroughly researched this topic, article 4 is published in the database. In their 2021 study, she and her colleagues sought ways to reduce the harm that pesticides can cause to the environment. Thanks to research by scientists, we can learn more about how herbicides work on bacteria and use the natural protection of these bacteria to clean contaminated sites. He initially studied individual bacteria, and then moved on to study how they interact with other living organisms in nature.

M. Shahid, P. Sharma, S. Singh, U.B. Singh and Y. Zhou have published 3 publications. Indian M. Shahid and Chinese Y. Zhou studied the toxic properties of pesticides and heavy metals, as well as the effects of bacteria on physiological stress in plants [11]. These scientists conduct regular research in the fields of bio-medicine, microbiology and environmental biotechnology. N.A. Agbodjato, O.O. Babalola, R. Bhardwaj and H.J. Chaudhary belong to a group of ten researchers, each with two publications.

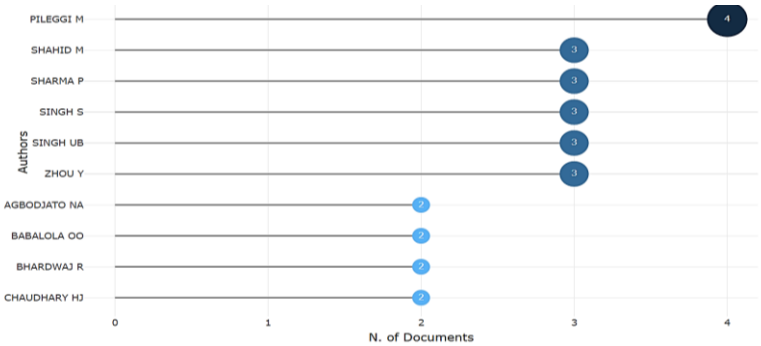


Figure 5 – Number of publications of the most active authors

The authors' Bibliometric analysis found that several research groups have actively contributed to the bioremediation of environments contaminated by pesticides and *Pseudomonas* bacteria. The largest number of publications was received by the Brazilian scientist M. Although he is owned by Pileggi, there has been sustained scientific activity from other researchers. This confirms that this is a relevant area of research developing at the international level. S. Singh defines molecular mechanisms of biorecovery, U.B. Singh investigated the role of root micro-organisms in protecting plants. R. Bhardwaj and his colleagues are studying how to make plants more resistant to heavy metals and pesticides in the environment. Among the growth harmonians, brasssisonosides and the use of polyamines are studied [12].

The keyword cluster, executed by VOSviwer, is shown in Figure 6. The first group is highlighted in green. Considered the keywords *Pseudomonas, bioremediation, bacteria, pesticides.* This cluster describes the decomposition of pesticides by micro-organisms, bacterial activity in soil, exposure to Pseudomonas bacteria. Microbiology and Environmental Science show that it is being studied whether Pseudomonas bacteria can break down pesticides by using them as an energy source.

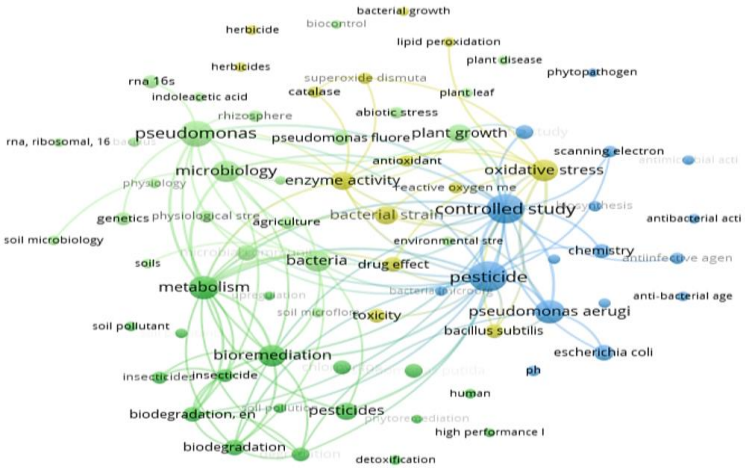


Figure 6 – Keyword cluster

Keywords on pesticide toxicity and antibacterial action in the blue cluster. This direction is aimed at studying the chemical properties of pesticides, their toxicity and antibacterial activity. Bacteria such as pesticides, *Pseudomonas aeruginosa* and *Escherichia coli* are considered to be the main objects of the study. The aim of these studies is to determine the drug action of pesticides and their antimicrobial activity. Studies in toxicology and chemistry can help to understand the impact of pesticides on the microbial community.

The Yellow Cluster studies how plants and bacteria respond to oxidative stress, the function of antioxidant enzymes including catalasm, and the physiological effects of pesticides on plants. Increased levels of active oxygen in cells due to pesticide exposure cause oxidative stress. However, *Pseudomonas* bacteria contribute to the reduction of this stress through catalastic and other enzymes. Jiang, Y., and his bioremedial ability was greatly improved by the introduction of genes degrading pesticides (parathion, 2,4-D) (mpd, tfdABCDEF) into the genome of *Pseudomonas putida* KT2440 in a study conducted by his colleagues [13]. In addition, the use of *Pseudomonas stutzeri* bacteria in combination with silver nanoparticles has optimized the physiological state of maize plants grown in water contaminated by chromium. This synergistic effect stimulates the synthesis of protective metabolites (flavonoids, phenols) in plants and reduces oxidative stress [14].

The map of research data shows that areas of science such as biomedication, microbiology, environmental biotechnology, toxicology, agriculture and plant physiology are closely related. This indicates that the topic is interdisciplinary.

Conclusion

In conclusion, the results of a systematic literature review provide quantitative and qualitative evidence of micro-organisms' effectiveness in reducing pesticide harm. An analysis of publications from 2010 to 2026 based on the *Scopus* database, *Researsh Gate*, showed a clear increase in

research activity. The total number of citations exceeds 600 in 2026, which confirms the scientific significance of this direction. As a result of the bibliometric analysis, it was found that the topic is in leading journals in biochemistry and molecular biology.

In general, the results show that bio-medicine is an effective means of maintaining balance and environmental cleanliness. It is important to implement this method to protect the environment. *Pseudomonas* bacteria feed on harmful coal hydrogen in the environment. Thanks to its unique ability to adapt easily to changes in genes, it has great potential for cleaning up land contaminated with pesticides and heavy metals. In the laboratory, these bacteria can remove more than 70% of heavy metals and up to 98% of pesticides. However, in real natural conditions these indicators fall to 10-25%, limiting their practical application. To address this shortcoming, priorities must be set in the direction of genetic engineering. In the future, *Pseudomonas* strains, enhanced by genetic engineering, adapted to natural conditions, and supplemented by advances from various fields of science, will open new opportunities for sustainable agriculture and environmental restoration.

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ПЕСТИЦИДТЕРМЕН ЛАСТАНҒАН ОРТАЛАРДЫ БИОРЕМЕДИАЦИЯЛАУДАҒЫ *PSEUDOMONAS* БАКТЕРИЯЛАРЫНЫҢ РӨЛІ: ӘДЕБИ ШОЛУ

Қазіргі уақытта агроөнеркәсіпте пестицидтердің қоршаған ортаға таралуы экожүйелердің тұрақтылығына, топырақ сапасына және адам денсаулығына елеулі қауіп төндіріп отыр. Бұл жаһандық экологиялық мәселені шешуде тиімді әдісі ретінде биоремедиация технологияларына деген қызығушылық артып келеді. Осы бағытта, жоғары метаболикалық белсенділігі мен жасанды химиялық заттарды ыдырату қабілеті бар Pseudomonas туысына жататын бактериялар ерекше ғылыми назар аударады. Бұл әдеби шолуда Pseudomonas бактерияларының пестицидтермен ластанған ортаны биоремедиациялаудағы рөлі туралы соңғы ғылыми зерттеулерге библиометриялық және мазмұндық талдау жасалды. Зерттеулердің нәтижелері бойынша, бұл тақырыптағы ғылыми жарияланымдар саны соңғы жылдары тұрақты өсіп келеді. Әсіресе, Индия мен Қытай бұл бағыттағы зерттеулерді қарқынды дамытып жатқан елдер ретінде айқындалды. Ғылыми еңбектердің басым бөлігі экология ғылымы, микробиология және биохимия салаларында шоғырланған. Осы зерттеу шеңберінде Prisma әдіснамасын қолдана отырып, Scopus дерекқоры негізінде 2010 жылдан 2026 жылға дейінгі кезеңдегі ғылыми жарияланымдарды іріктеу жүргізілді. Scopus деректер базасынан мақалаларды іздеу «pesticide stresss» және «pseudomonas» кілт сөздерін қолдану арқылы жүзеге асырылды. Кілт сөздермен іздеу барысында 91 мақала таңдап алынып, іріктеу кезінде ең маңызды 20 мақала қарастырылды. Талдауға тек ағылшын тілінде жарияланған рецензияланған мақалалар енгізілді.

Зерттеулер Pseudomonas бактерияларының пестицидтерді ыдыратуға, тотығу стрессін азайтуға және ластанған топырақ микрофлорасын қалпына келтіруге белсенді қатысатынын көрсетеді. Pseudomonas бактерияларының азотты фиксациялау, ауксин бөлу, фитогармондар түзу арқылы өсімдіктің өсуін ынталандыру, фитопатогендерді жою, антибиотик түзу қасиеттері көп зерттелген. Бактериялардың абиотикалық стресстерге (құрғақшылық, тұздану) әсері көп айтылғанымен, олардың пестицидтік стрессті жеңілдету қабілеті туралы мәліметтер әлі де аз. Сонымен қатар бактериялардың ферменттік жүйелері мен генетикалық механизмдерінің пестицидтерді түрлендіруде және минералдаудағы рөлі зерттелді. Әдеби деректерді талдау негізінде Pseudomonas бактерияларының экологиялық биотехнологиядағы маңызды биологиялық кешен екендігі расталды. Оларды пестицидтермен ластанған топырақ пен су экожүйелерін тазарту үшін қолдану, қоршаған ортаны тұрақты басқарудың тиімді стратегияларының бірі болып табылады.

Түйін сөздер: *Pseudomonas бактериялары, абиотикалық стресс , пестицид, биоремедиация, VOSviwer, Bibliometrix.*

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РОЛЬ БАКТЕРИЙ РОДА *PSEUDOMONAS* В БИОРЕМЕДИАЦИИ ПЕСТИЦИДНО-ЗАГРЯЗНЁННЫХ СРЕД: ОБЗОР ЛИТЕРАТУРЫ

В настоящее время распространение пестицидов в окружающей среде в агропромышленном комплексе представляет серьёзную угрозу для устойчивости экосистем, качества почвы и здоровья человека. В связи с этим возрастает интерес к технологиям биоремедиации как к эффективному методу решения данной глобальной экологической проблемы. В этом направлении особое научное внимание привлекают бактерии рода Pseudomonas, обладающие высокой метаболической активностью и способностью разлагать синтетические химические вещества. В данном литературном обзоре проведён библиометрический и содержательный анализ последних научных исследований, посвящённых роли бактерий Pseudomonas в биоремедиации сред, загрязнённых пестицидами. По результатам исследований установлено, что количество научных публикаций по данной тематике в последние годы стабильно растёт. Особенно выделяются Индия и Китай как страны, активно развивающие исследования в этом направлении. Основная часть научных работ сосредоточена в областях экологии, микробиологии и биохимии. В рамках данного исследования с использованием методологии PRISMA был проведён отбор научных публикаций из базы данных Scopus за период с 2010 по 2026 год. Поиск статей в базе данных Scopus осуществлялся с использованием ключевых слов «pesticide stress» и «pseudomonas». В результате поиска по ключевым словам было отобрано 91 статья, из которых при дальнейшем отборе были рассмотрены 20 наиболее значимых публикаций. В анализ были включены только рецензируемые статьи, опубликованные на английском языке.

Исследования показывают, что бактерии Pseudomonas активно участвуют в разложении пестицидов, снижении окислительного стресса и восстановлении микрофлоры загрязнённых почв. Свойства бактерий Pseudomonas, связанные с фиксацией азота, выделением ауксинов, стимулированием роста растений посредством синтеза фитогормонов, подавлением фитопатогенов и продуцированием антибиотиков, достаточно хорошо изучены. Несмотря на то, что влияние бактерий на абиотические стрессы (засуха, засоление) широко освещено в научной литературе, сведения об их способности снижать пестицидный стресс всё ещё ограничены. Кроме того, была изучена роль ферментативных систем и генетических механизмов бактерий в трансформации и минерализации пестицидов. На основе анализа литературных данных подтверждено, что бактерии Pseudomonas являются важным биологическим компонентом экологической биотехнологии. Их использование для очистки почвенных и водных экосистем, загрязнённых пестицидами, является одной из эффективных стратегий устойчивого управления окружающей средой.

Ключевые слова: *бактерии Pseudomonas, абиотический стресс, пестицид, биоремедиация, VOSviewer, Bibliometrix.*

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ҚАЙТАЛАМА ЕТ ЖӘНЕ БАЛЫҚ ШИКІЗАТЫНАН АҚУЫЗ ГИДРОЛИЗАТЫН (ПЕПТОН) АЛУ ТЕХНОЛОГИЯСЫН ӘЗІРЛЕУ

Аңдатпа: *Мақалада қайталама ақуыз шикізатын қышқылды-ферментативті өңдеу әдісін зерттеу нәтижелері ұсынылған. Жұмыстың мақсаты – биологиялық белсенділігі жоғары ақуыз гидролизі негізінде құрғақ пептон алудың технологиялық режимдері мен параметрлерін әзірлеу. Зерттеу нысаны гидролиз әдістері болды. Жануарлар протеазаларының ферменттік кешенінің гидролиздеу әсерінің ет және балық шикізатының қасиеттерінің өзгеруіне әсері зерттелді.*

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