SRI VENKATESWARA

INTERNSHIP RESEARCH PROGRAM FOR RESEARCH IN ACADEMICS

(SRI-VIPRA)

Project Report of 2025-26: SVP-2503

Title:Screening of Indigenous Soil Microorganisms for Pesticide Bioremediation Potential

IQAC

Sri Venkateswara College

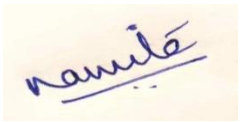
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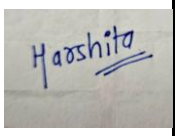
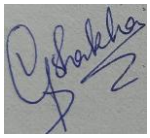
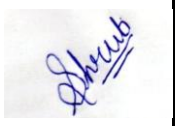
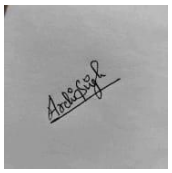
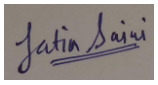
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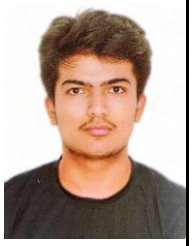
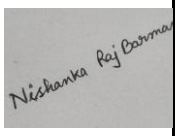
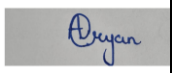
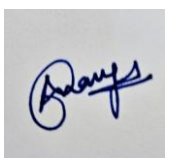
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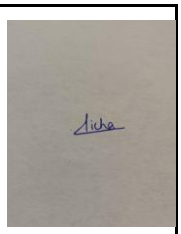
Title:Screening of Indigenous Soil Microorganisms for Pesticide Bioremediation Potential

Name of the mentor	Dr. Namita Nayyar	Dr. Richa Mishra
Department name	Zoology	Zoology
Designation	Assistant Professor	Assistant Professor
Photo		
Signature		

List of students under the SRIVIPRA Project

S.no	Photo	Name of student	Roll number	Course	Signature
1.		Harshita Jha	2022022	B.Sc hons zoology	
2.		Vishakha Dutta	2023048	B.Sc Zoology hons	
3.		Shruti Mishra	1322039	B.Sc hons Biological Sciences	
4.		Rhythm Arora	2023021	B.Sc Zoology hons	
5.		Archi Singh	1122084	B.sc Life sciences	
6.		Jatin Saini	1123164	B.Sc Life sciences	

7.		Meenal Aishwari	1123182	B.Sc Life Sciences	
8.		Prakriti Singh Chahar	1122152	B.Sc Life Sciences	
9.		Ankush	1122090	B.Sc Life Sciences	
10.		Aman Deswal	2023036	B.Sc hons zoology	
11.		Nishanka Raj Barman	2023013	B.Sc hons zoology	
12.		Aryan Chaudhary	2022040	B.Sc hons zoology	
13.		Ananya	2022018	B.Sc hons zoology	

14.		Richa Prabhakar	1123007	B.Sc (p)Life Sciences	
15.		Riya Pal	1122135	B.Sc Life sciences	



Signature of Mentor

Certificate of Originality

This is to certify that the aforementioned students from Sri Venkateswara College have participated in the summer project SVP-2503 " Title: Screening of Indigenous Soil Microorganisms for Pesticide Bioremediation Potential."

The participants have carried out the research project work under my guidance and supervision from July 2025 to February 2026.

The work carried out is original and carried out in an offline mode.



Signature of Mentor

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INTRODUCTION

Pesticides in Modern Agriculture

Current agricultural techniques rely heavily on the use of pesticides for crop protection and to ensure there are sufficient amounts of food available for everyone. Pesticides in their most simplistic form are synthetically created chemicals manufactured on a large scale in industries in order to tackle the problem of agricultural pests, fungi, weeds, and even crops themselves. The pesticides that are most widely used contain organophosphates, organochlorines, carbamates, and pyrethroids.

Although intended to increase crop yield by reducing the menace of pests, pesticides pose a major threat to the environment. These pesticides are extremely persistent and remain in the environment for over decades. The frequent, indiscriminate and large-scale use of these chemicals has had a negative effect on the soil, which receives the majority of these contaminants. Pesticides contribute to the increase in crop-yield, but the amounts that reach the pests intended to be targeted are inadequate (Uqab et al., 2016; Kumar et al., 2018) hence resulting in over use.

The presence of pesticides within the ecosystems has resulted in severe adverse effects. Repeated deployment of agricultural chemicals has resulted in the development of resistance to these chemicals by pests, and has created an imbalance in the ecosystem. This has created a need for the use of effective remediation strategies to the problem. (Mali et al., 2022).

Environmental Fate and Persistence of Pesticides in Soil

Once pesticides are applied on their target sites, there are many physical, chemical, and biological transformations they undergo which will determine their environmental fate. Majorly, the pesticide sinks in soil, where they can bind to organic matter, undergo volatilization, leach to groundwater, and remain as bound residues for a long time. Soil pH, moisture, texture, temperature, and microbial activity are crucial for their persistence (Kumar et al., 2018). Research done on persistent organochlorine pesticides, for example, hexachlorocyclohexane (HCH), shows that pesticide residues in soil can last for decades, and especially at sites of dumping and/or areas with high levels of agricultural pesticide treatments.

Research done on sites contaminated with HCH has shown that natural attenuation is insufficient for complete detoxification, which highlights the importance of more aggressive efforts to remediate contaminated soils (Garg et al., 2016).

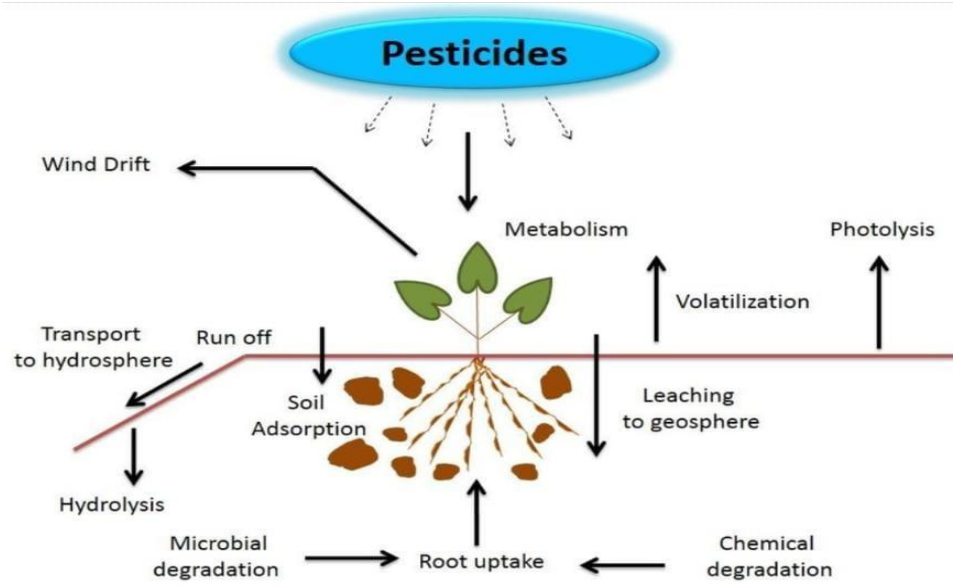


Figure 1. Environmental fate of pesticides in soil ecosystems (source: Kumar et al., 2018).

Toxicological Effects of Pesticides on Soil Ecosystems

Soil microorganisms, plants, animals, and even humans can be harmed due to pesticide residues. Organophosphate pesticides block the activity of acetylcholinesterase, which causes neurotoxicity in both vertebrates and insects. (Kumar et al.2018)

The prolonged exposure, even in lower concentrations, can lead to substantial physiological and biochemical changes. In the soil ecosystem, pesticide toxicity changes the microbial diversity and lowers the enzymatic activity that are crucial for nutrient cycling. Soil ecosystem toxicity, long-lasting contamination, the food webs of microorganisms, and the diminished resilience of soil ecosystems suffer the most from the added problems of the soil ecosystem toxicity. Pesticide metabolites, as well as unaltered pesticides, can be complex and difficult to remediate due to the fact that they sometimes are equally as toxic. (Mali et al., 2022).

Pesticide Resistance: Types and Mechanisms

The repeated use of a pesticide creates a strong selective pressure on the target and non-target pests and microorganisms alike, causing the development of pesticide resistance. Most types of resistance fall into three general categories: physiological resistance, behavioural resistance, and metabolic resistance. (Uqab et al., 2016).

Metabolic resistance is particularly relevant in soil, where microorganisms develop detoxifying mechanisms for the pesticide in question. Resistance mechanisms among microbes can include enzyme hydrolysis, modification at target sites, activation of efflux pumps, and genetic change

caused by horizontal gene transfer. Among pesticide resistant microorganisms, the resistant strain's ability to degrade the pesticide usually comes first. This is because the resistant strains often use the pesticide as a nutrient. (Kumar et al., 2018).

This is why a pesticide resistant strain is often a key component of a successful microbial bioremediation system.

Limitations of Conventional Remediation Techniques

Methods such as excavation, incineration, chemical oxidation, and soil washing have been used to remove pesticide contaminants. These methods face several challenges, including cost, amount of energy and manpower used, and disturbance to the surrounding ecosystem. Chemical treatments sometimes create toxic byproducts, and physical removal creates secondary pollution. Additionally, conventional methods are impractical and often fail to restore biological integrity of soils. These failures illustrate the need for a new remediation system that is sustainable and biologically driven. (Uqab et al., 2016).

Bioremediation as an Eco-Friendly Alternative

Using microorganisms to break down contaminants in ecosystems that have been polluted is known as bioremediation. The method relies on the ability of microorganisms to treat pesticide biosystems. For the past several decades, bioremediation has stood out as a very valuable approach compared to its alternative physical and chemical remediation techniques, especially on pesticide-contaminated soils. (Uqab et al.; Kumar et al., 2018).

Different from the physical and chemical remediation approaches, bioremediation is environmentally safe, economical, and brings back the biological quality of the soils that were damaged. The bioremediation process can cause the pesticide to break down into harmless end products, such as water and carbon dioxide. Because of this, bioremediation is a multi-faceted process that increases the health of ecosystems and adds to the fertility of soils. (Mali et al., 2022).

One of the ways to classify bioremediation methods are the amount of human interaction involved, and the origin of the degrading microbes.

One of the methods, termed **intrinsic bioremediation, or natural attenuation**, relies on the natural ability of the native microbes to cause bioremediation of the contaminants, but with no human stimulation. While it most definitely is the case that bioremediation of the contaminants in natural soils does happen, it is in many cases too slow to be of major use. This is particularly true in soils of high toxicity, particularly soils where soil pesticides are present in amounts that cannot be tolerated by the microbes. (Kumar et al., 2018).

One method, termed **biostimulation**, tries to counteract the negative bioremediation effects of soil pesticides by adding nutrients, and or soil electron donors, and or soils in which the oxygen has been enhanced, with the hopes of accelerating the degradation of soil pesticides. The addition of nitrogen, phosphorus, and certain soil microbes that act as organic substrates, can be used to enhance the growth of the soil microbes, increase the production of the microbial enzymes needed for the biodegradation to happen and also speed up the process of biodegradation. Studies on soils that have been contaminated with HCH, have shown that by simply adding nutrients, the degradation of some of the isomers of HCH improved, but the nutrients alone did not allow for full detoxification of the soil. (Garg et al., 2016).

The term **bioaugmentation** is used to describe the process where specific soil microbes that can degrade pesticides are added to contaminated soils, which is meant to increase the speed at which the bioremediation of the soil is accomplished.

The added microbes can be individual strains or a mixture of many different microbial strains (consortia) that have been shown to have the ability to degrade many different molecules of a pesticide.

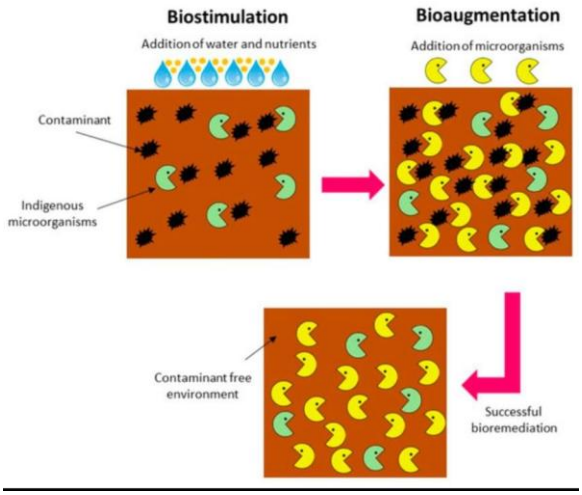


Figure 2. Different bioremediation strategies employed for pesticide-contaminated soils (Source: Garg et al., 2016).

Unfortunately, the newly added strains can sometimes be dominated by the pre-existing soil microbes, which can also be augmented by added nutrients, and as a result, the newly added microbes may not be as active as they could be. Studies have shown that the most effective bioremediation of contaminated soils is that which combines the biostimulation and the bioaugmentation methods. (Uqab et al., 2016).

Research at HCH dumpsites demonstrated that the higher degradation rates achieved with microbial consortia plus nutrient supplementation were due to the positive effect of synergistic interactions.

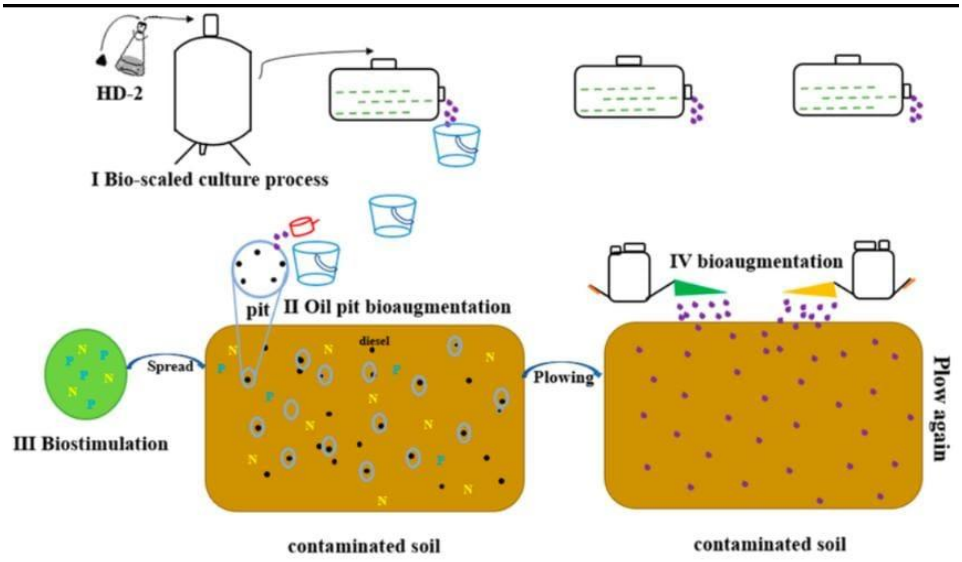


Figure 3: Laboratory and field scale bioremediation of HCH contaminated soils (source: Garg N et al., 2016).

Microbial Mechanisms Underlying Bioremediation

Microbial bioremediation of pesticides involves several degradative processes that modify pesticides at the molecular level by chemical reaction mechanisms. These include the enzymatic catalysis of hydrolysis, oxidation, and other chemical processes depending on the alterable chemical structure of the pesticide, which include reduction, dechlorination, and dealkylation. Certain organophosphate pesticides are mainly broken down through the hydrolysis of phosphoester bonds, which then leads to a decrease in toxicity of the pesticide. These processes are exemplified by a range of specific microbial enzymes, including stearases, phosphotriesterases, monooxygenases and haloalkane dehalogenases. (Kumar et al., 2018).

Lin genes are particularly involved in HCH degradation that catalyzes successive dechlorination of a number of toxic isomers to produce much less toxic metabolites. Although these degradation products may persist in the environment, they are much less toxic than the original compound to the extent of being considered as effective detoxification products. On the other hand, some pesticides may serve as the primary carbon and energy source for microbial organisms. These pesticides are effectively degraded through a mechanism referred to as aerobic metabolic degradation. Alternatively, some pesticides may be degraded by chemical transformation that occurs during the metabolism of other substrates. This mechanism is known as co-metabolic degradation and is also effective in pesticides removal from soil. (Garg et al., 2016).

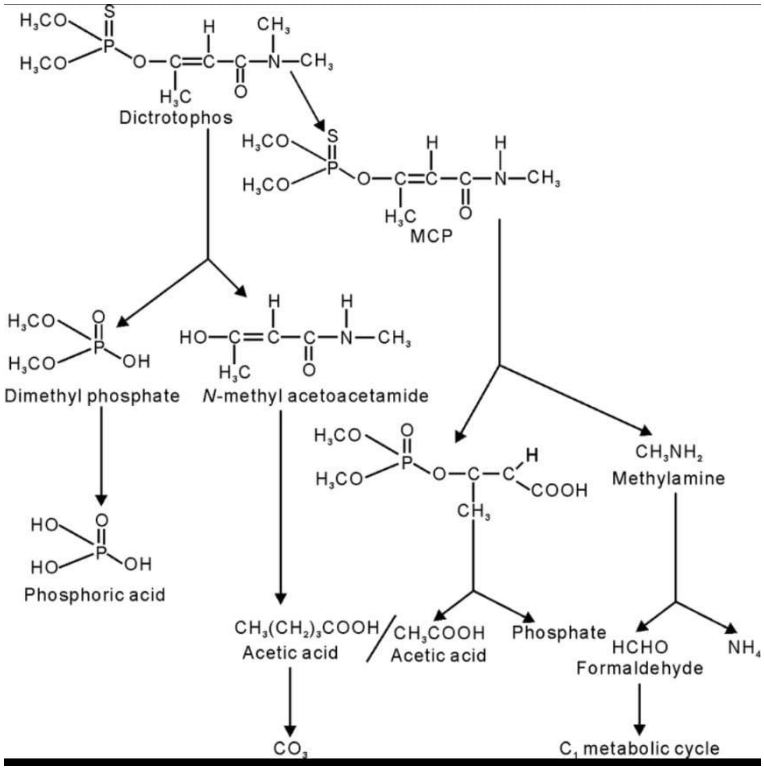


Figure 4. Microbial degradation pathway of organophosphate/HCH pesticides mediated by specific enzymes (source: Kumar et al., 2018).

Advantages of Bioremediation Over Conventional Methods

Bioremediation is cost-effective, low-energy, and can be implemented at contaminated locations without needing soil removal. Moreover, bioremediation retains soil structure and microbial diversity, in contrast to chemical or thermal treatments that may harm soil life. Adaptability to a wide range of environmental conditions is another factor influencing bioremediation's overall success, particularly in the case of indigenous microorganisms. Local 'super stressors' at a site may be offset by the presence of indigenous microbes, and they typically remain resilient to changing temperature, moisture, and pH conditions, further contributing to bioremediation's success. (Uqab et al., 2016; Mali et al., 2022).

Role of Indigenous Soil Microorganisms

Native soil microorganisms have acclimatized to the local environmental settings as well as to the long-term exposure to pesticides. Recurrent pesticide application leads to change in the soil microflora in favor of those possessing tolerance to the pesticide, as well as the ability to break down those compounds. (Uqab et al., 2016).

Compared to the introduced microflora, the indigenous strains survive better, have greater metabolic efficiency, and are more ecologically harmonized. Farm soil and contaminated reservoir studies have indicated that certain indigenous bacteria, including those from the *Pseudomonas, Bacillus*, and *Sphingobium* genera, have the capacity to breakdown chlorpyrifos, phorate, and several other organophosphates. (CWE Journal, 2008; Jariyala et al., 2018).

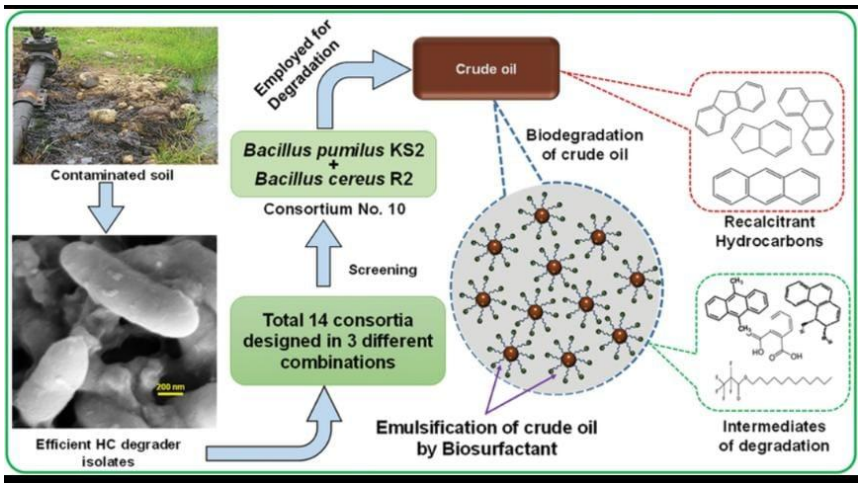


Figure 5. Microbial Consortium-Mediated Pesticide Degradation (Source: Jariyala et al., 2018).

Screening of Indigenous Microorganisms for Bioremediation

Screening refers to the isolation, characterization, and evaluation of indigenous microorganisms concerning their potential to degrade pesticides. This process focuses on determining efficient degraders and evaluating their growth kinetics, degradation modifications, and adaptability. The screening studies are the basis for the formulation of bioremediation strategies for specific sites. (Academia.edu, 2014).

In addition, pilot scale screening helps to choose the best of the robust microbial candidates before the application in the field, thereby reducing the guesswork and increasing the result of the remediation. These preliminary studies are critical for the development of field applicable technologies for the restoration of soils from the laboratory research.

Global Usage and Economic Importance

Worldwide agricultural consumption is forecast to increase from approximately 4.3 million metric tonnes in 2023 to around 4.41 million metric tonnes in 2027, with the Americas accounting for more than half of the world's total pesticide use.(*Global Agricultural Use of Pesticides 2023-2027*, n.d.) The global pesticide and chemical market size was valued at

$104.46 billion in 2024 and is expected to grow to $113.13 billion in 2025 at a compound annual growth rate of 8.3%. (ltd, n.d.) Brazil leads the world in pesticide consumption, using approximately 719.5 thousand tonnes annually, followed by the United States(457.4 thousand tonnes), Indonesia(283.3 thousand tonnes), China(233.9 thousand tonnes) and Argentina(241.5 thousand tonnes).(*Pesticide Usage by Country 2025*, n.d.) According to the Food and Agriculture Organization, total pesticide use in agriculture was 3.70 million tonnes of active ingredients in 2022, marking a 4% increase from the previous year.(*Pesticide Usage by Country 2025*, n.d.)

Bioaccumulation and Food Chain Transfer

Bioaccumulation represents a critical environmental concern, particularly for lipophilic pesticides that readily dissolve in fatty tissues, with persistent organic pollutants such as DDT accumulating in organisms over time to reach concentrations many times higher than those in the surrounding environment. (admin, 2025) Biomagnification occurs when pesticide concentration increases at successive trophic lewithin food webs, with top predators including birds of prey, marine mammals, and fish-eating species bearing the highest pesticide burdens.(admin, 2025; Tison et al., 2024) Organochlorines and Organophosphates are often cited as “problem chemicals” because they’re both persistent and bioaccumulative, remaining as residues in soil and water while gradually building up in plants, animals, and humans. (Mishra et al., 2025)

Methodology

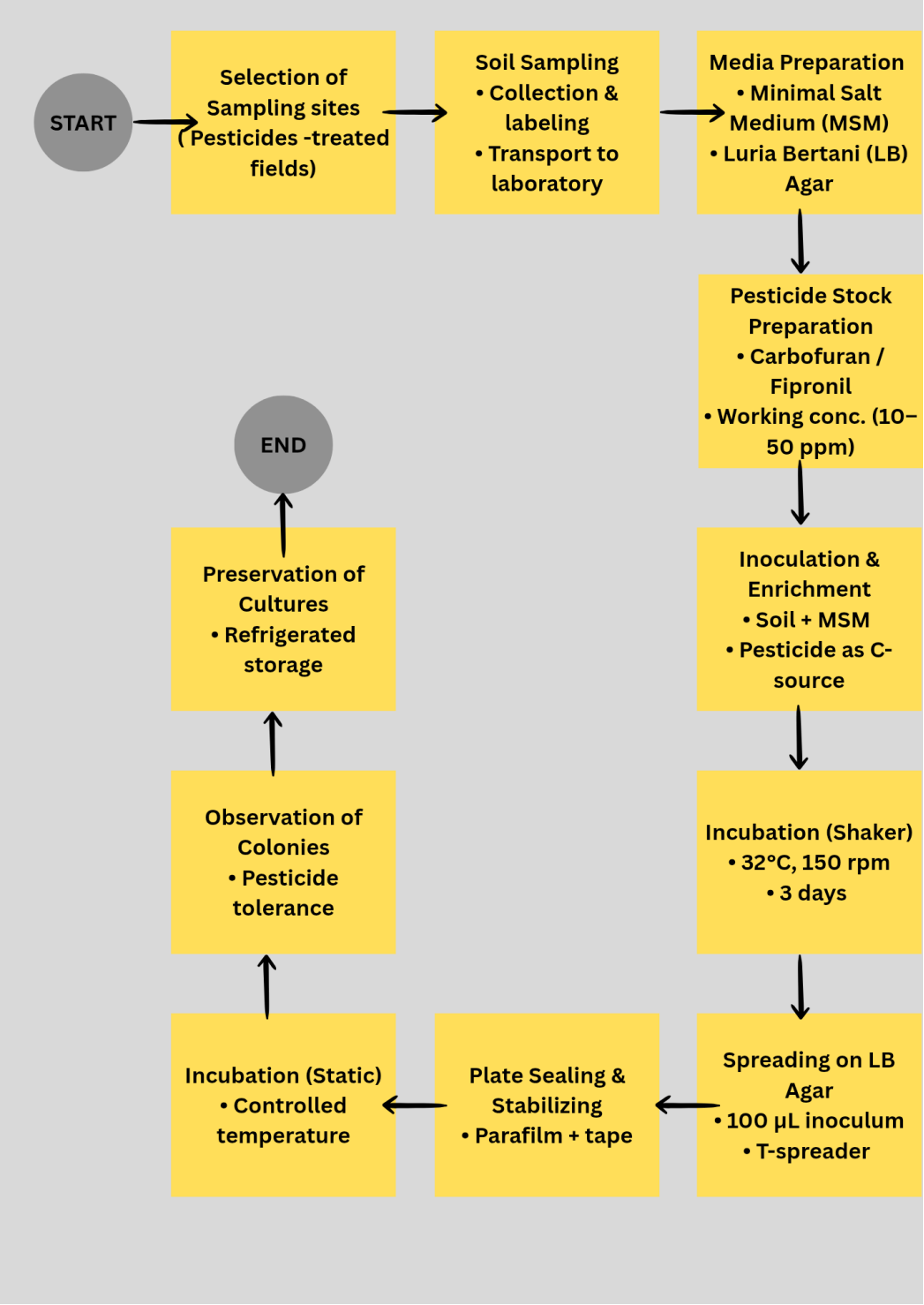


Figure 6: Descriptive Flow Chart of the Experimental Procedure

Our study was carried out to isolate and enrich indigenous soil microorganisms with potential pesticide tolerance and degradation ability. It involved systematic collection of soil samples

from selected agricultural sites, followed by enrichment of microbial populations using selective culture techniques. Standard microbiological methods were employed for media preparation, incubation, and maintenance of cultures.

Soil Sampling

Soil samples were collected from agricultural fields with a known history of pesticide use. Sampling was carried out by removing the debris and collecting soil from the upper layers. Samples from multiple points within each site were obtained. The collected soil was properly labeled, and transported to the laboratory. The fields were captured using a GPS camera, for proper location coordinates along with time and date. Apart from the soil, small amounts of pesticide samples were also collected from the same fields.

- Site 1 : Hisar, Haryana

  Pesticide - RoundUp, Weedkill 508

- Site 2 : Jind, Haryana

  Pesticide - Carbofuran, Fipronil

- Site 3 : Jawahari,Haryana

  Pesticide - Ferterra, Kartap, RoundUp

- Site 4 : Burari, Haryana

  Pesticide - Coragen, Cyper 25 Mono

- Site 5 : Mirchpur, Haryana

  Pesticide - Coragen, Masterstroke, Durmex Plus, Defender

- Site 6 - Ganga Parshad, Jharkhand

  Pesticide - Chlorpyrifos



Figure 6 : Field sampling at Hisar, Haryana showing pesticide that is used

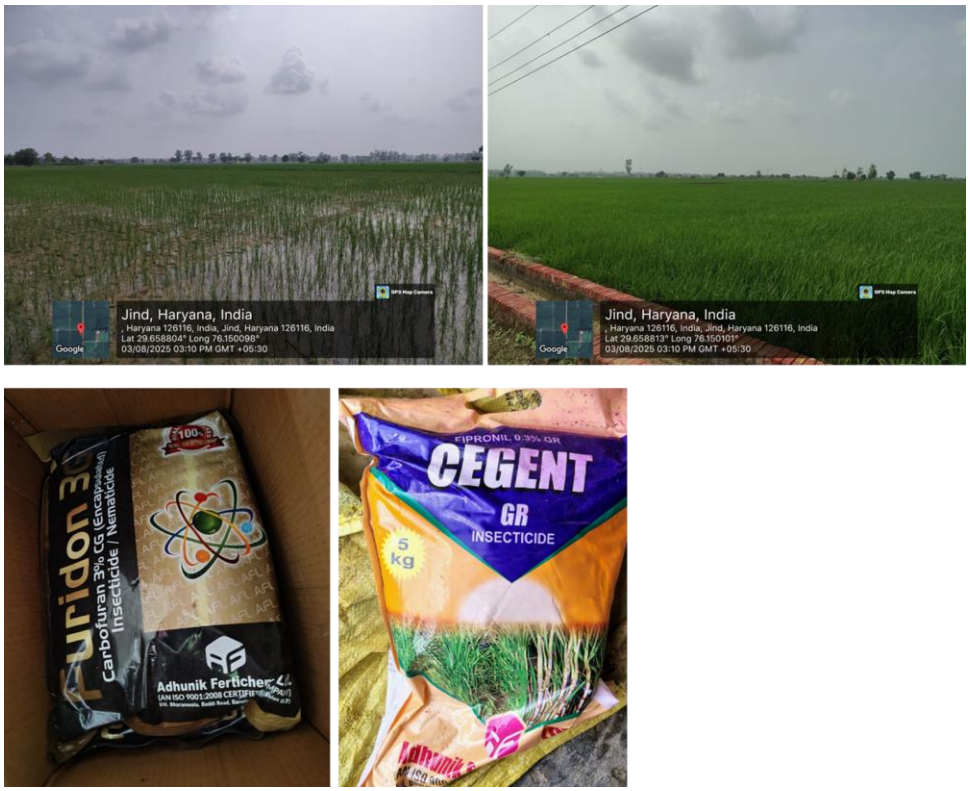


Figure 7 : Field sampling at Jind, Haryana and pesticide sample collected

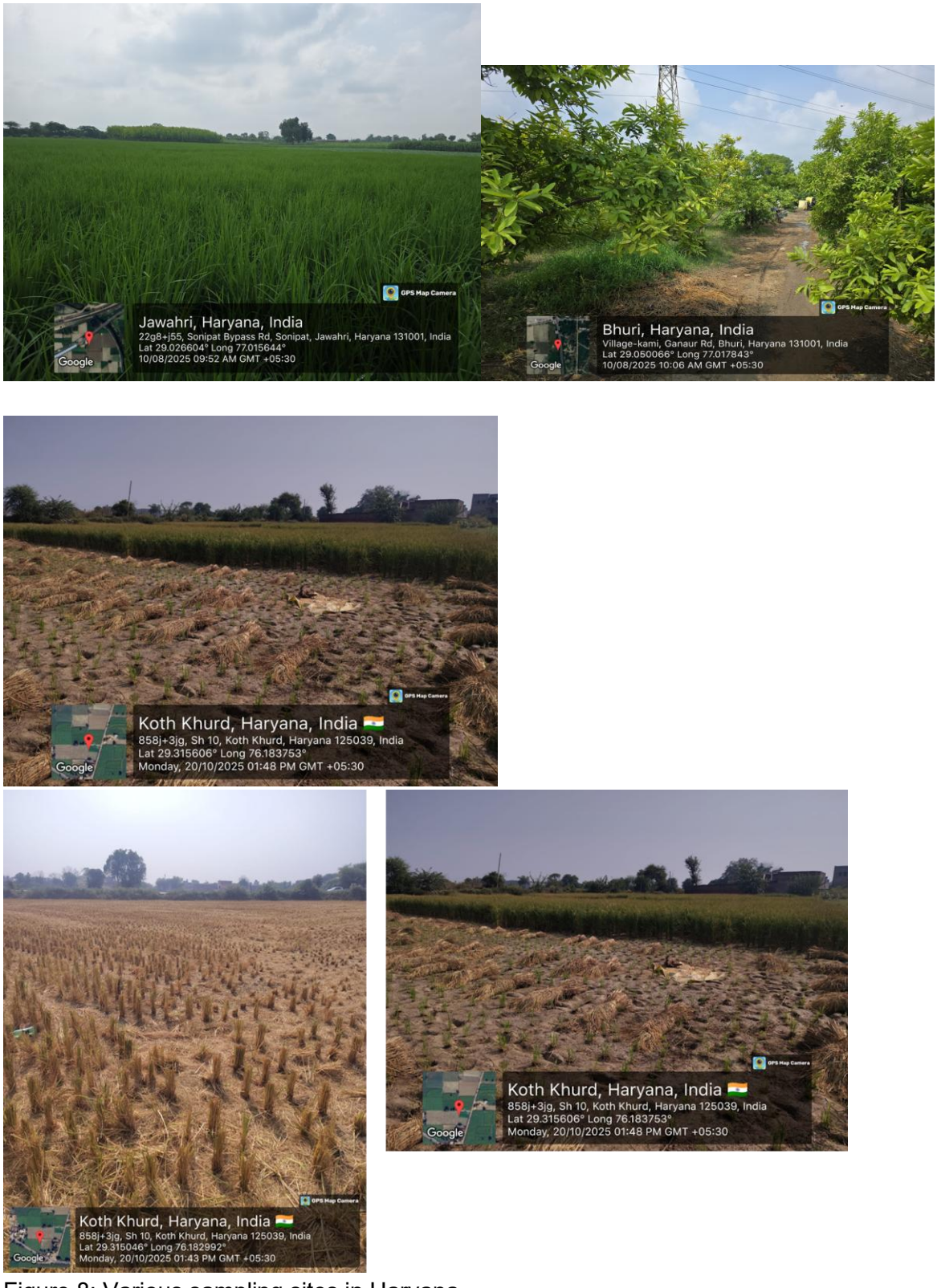


Figure 8: Various sampling sites in Haryana



Figure 9: Sampling site in Jharkhand

Media Preparation

Minimal Salt Media (MSM)

Minimal Salt Medium (MSM) was prepared using standard protocols to support the selective growth of pesticide-tolerant microorganisms. The medium contained essential inorganic salts required for microbial growth, while the pesticide under study served as the sole or primary carbon source. The solution was prepared by sequentially adding the required salts to MilliQ water. Na_2HPO_4, NaCl, and NH_4NO_3 were dissolved first, followed by $MgSO_4$ and $CaCl_2$. $FeSO_4$ was added last to prevent precipitation. The pH was adjusted to 7.0–7.2 using 1 N HCl or NaOH, and the final volume was made up to 1 L with MilliQ water. The solution was sterilized by autoclaving at 121 °C for 15 minutes. It was stored properly until used.

Luria Bertani Media (LB)

LB agar media was prepared using standard protocols by dissolving the required components in distilled water. 16g of LB Agar Miller powder was dissolved in 400ml of water and the medium was sterilized by autoclaving. After cooling, the medium was poured under laminar flow hood into sterile petri plates and allowed to solidify before use.



Figure 10: Luria Bertani media used for plating

Pesticide Stock Preparation

Stock solutions of carbofuran and fipronil were prepared by dissolving the required amount of each pesticide in organic solvents. From these stocks, appropriate volumes were taken and diluted to obtain the desired working concentrations for the experiment.

ISOLATION AND ENRICHMENT

INOCULATION

Soil samples (0.3 g) were inoculated into 60 mL of sterile Mineral Salt Medium (MSM) supplemented with the target pesticide, furidon (carbofuran), as the sole carbon source. A stock solution of carbofuran (20 mg mL^{-1}) was prepared in acetone, and appropriate volumes were added to obtain final concentrations of 10, 20, 30, 40, and 50 ppm. Five enrichment flasks were established with progressively increasing pesticide concentrations to selectively promote the growth of pesticide-tolerant and degrading microorganisms. All inoculation procedures were performed inside a laminar airflow cabinet to maintain sterile conditions.

Following inoculation, the flasks were incubated in a rotary incubator shaker at 32 °C and 150 rpm for three days to facilitate microbial growth. Microbial growth was monitored periodically.



Figure 11: Image showing inoculated flasks in an incubator shaker.



Figure 12: Image showing Shaker Incubator

SPREADING

This step marks the beginning of the biological testing phase where the soil microbes are introduced to the growth medium. Once the LB (Luria-Bertani) agar had solidified inside the 12 petri dishes, a precise volume of 100 µL of the prepared (soil + pesticide) solution was transferred onto the center of each plate using a micropipette. This specific volume ensures a consistent concentration of bacteria and chemicals across all test subjects.

Following the pipetting, a spreading technique was performed to distribute the liquid evenly across the entire surface of the agar. This is critical for isolating individual bacterial cells; without spreading, the bacteria would grow in a single, unreadable clump.



Figure 13: Spreading done using T- spreader

The experiment was organized into a dosage gradient to test how different levels of pesticide toxicity affect bacterial survival:

10 ppm & 20 ppm: Two petri dishes each were used for these lower concentrations to observe initial sensitivity.

30 ppm: Four petri dishes were used here, likely serving as a central focus point for the data set.

40 ppm & 50 ppm: Two petri dishes each were used for these high-strength concentrations to test for extreme bacterial resistance.

Pesticide Concentration	Solution per Plate	Number of Petri Dishes	Total Volume Used
10 ppm	100 µL	2	200 µL
20 ppm	100 µL	2	200 µL
30 ppm	100 µL	4	400 µL
40 ppm	100 µL	2	200 µL
50 ppm	100 µL	2	200 µL
Total	—	12 Dishes	1.2 mL

Table 1: Pesticide concentrations, number of Petri dishes, and total solution volume used.

PLATE SEALING & STABILIZATION

After the spreading of the soil-pesticide solution was completed, each of the 12 petri dishes was meticulously sealed around the edges using parafilm, and then further reinforced with a double layer of tape. This process is vital for maintaining the internal environment of the agar, as it prevents the nutrient media from dehydrating and cracking during the long incubation period. The parafilm acts as a semi-permeable membrane that allows for minimal gas exchange while blocking out external contaminants like dust or mold spores that could skew the results. By double-securing with tape, you ensured that the lids remained firmly attached, preventing any accidental exposure to the outside air when moving the plates to the incubator.



Figure 14: Sealed plates

INCUBATION PARAMETERS & ENVIRONMENTAL CONTROL

Following the sealing process, all the petri dishes were placed into an incubator to begin the growth phase. The primary goal of this step is to provide a stable, controlled temperature that mimics the natural environment where soil bacteria thrive, allowing them to metabolize the nutrients in the LB agar. The incubator was set to rpm = 0, which indicates a static incubation environment. Unlike liquid cultures that often require shaking to distribute oxygen, these solid agar plates must remain perfectly still to allow individual surviving bacteria to settle and grow into visible, distinct colonies without being disturbed or smeared across the surface.



Figure 15: Petri dishes in an incubator

OBSERVATION

The plates were checked regularly for the growth of bacterial colonies.

PRESERVATION & RESOURCE MANAGEMENT

The final step in the setup phase involved the careful storage of all remaining materials for future experimental use. 400 mL of LB broth was saved along with the 5 original flasks containing the soil and pesticide mixtures. By placing these materials in a refrigerator, we effectively lowered the temperature to a point where biological activity and chemical degradation are significantly slowed down. This ensures that the nutrient media remains fresh and the bacterial samples in the flasks do not continue to multiply or die off rapidly, allowing to maintain a consistent "stock" for any follow-up testing or if needed to repeat a specific part of the trial.

Results and Discussion

Viable microbial population was observed in the cultures obtained from the soil with high concentration of pesticides. The standard culture techniques were used to isolate the indigenous soil microorganisms which are potentially tolerant to agricultural pesticides and possess the capability to degrade these pesticides. Following incubation for 72–96 hours, microbial growth was observed on the culture plates.

The significant finding was the appearance of distinct orange pigmented bacterial colonies exhibiting circular morphology. In microbial bioremediation, such pigmentation is observed in pesticide - tolerant bacteria . The pigment indicates carotenoid production ,which serves to protect against the oxidative stress encountered during the metabolic degradation of toxic compounds. Thus, highlighting their adaptive response and role in pesticide degradation.

Some morphologically similar white ,opaque circular colonies of bacteria were also observed in the culture plates in addition to pigmented colonies. Pesticides like carbofuran and fipronil are recalcitrant , which require cooperative action of different populations of microbes for the effective breakdown of these complex compounds.

Several culture plates also exhibited extensive growth of bacterial mat indicating high microbial activity and rapidly proliferating bacteria. These bacteria generally thrive on the by-products produced by the pesticide degrading microbes. The consortia thus contains diverse soil borne microbial populations which are widely used as the primary agents of pesticide degradation and detoxification in agricultural soil.

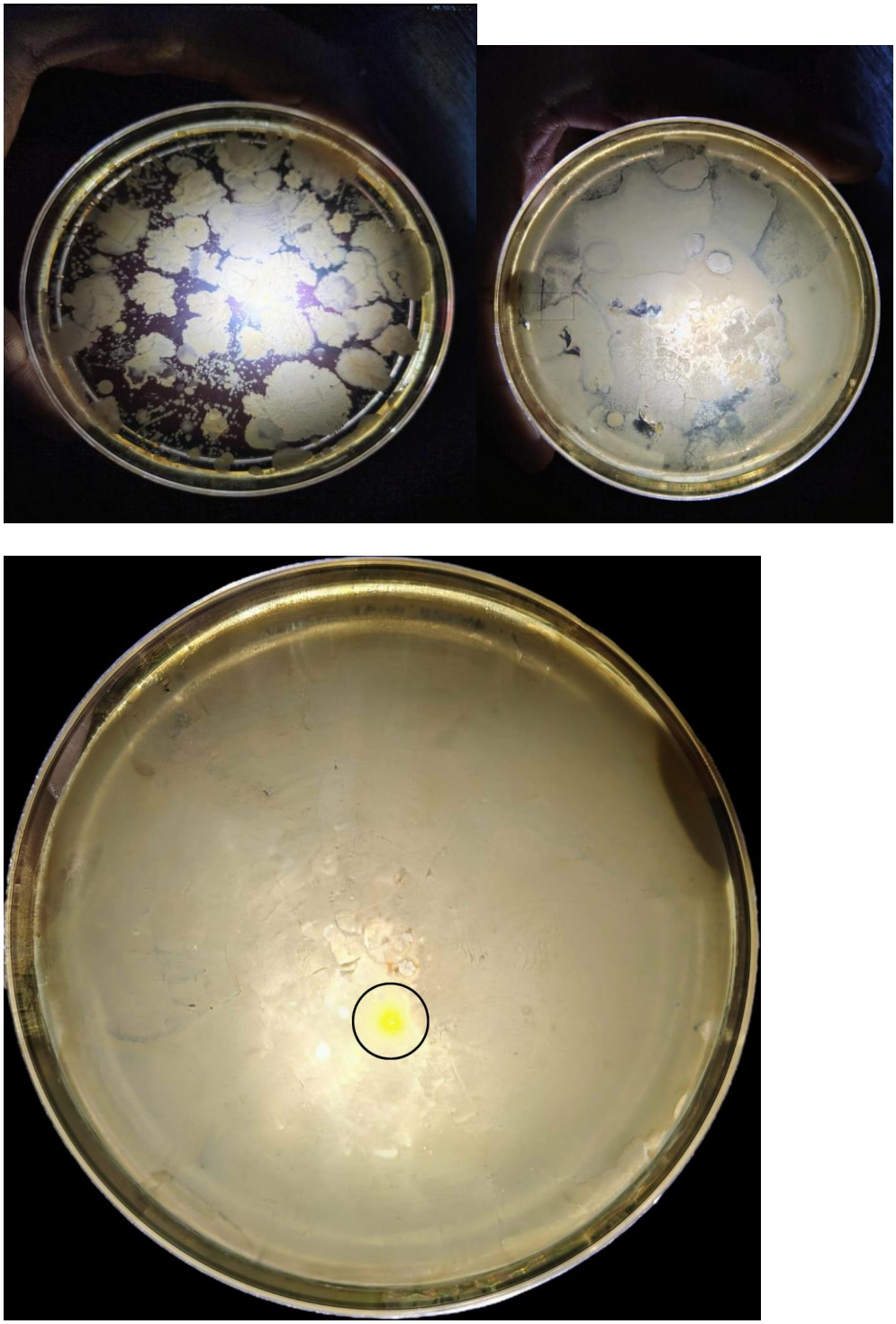


Figure 16: Orange coloured colonies of bacteria.

Discussion

In the present study, an emphasis was laid on the isolation and enrichment of native soil populations endowed with the capacity for survival and degradation of predominantly used agricultural pesticides, namely carbofuran and fipronil. Agricultural soil that is recurrently subjected to the usage of these types of pesticides would create an environment for the emergence of microorganisms with adaptive metabolic activity that would allow them survival on these foreign compounds. Thus, the isolation of these native populations is an environmentally beneficial method of bioremediation.

In particular, the enrichment of the samples using Minimal Salt Medium (MSM), with pesticides included and enriched as the initial carbon source, was particularly significant for the selective encouragement of the proliferation of tolerant microorganisms. Minimal Salt Medium essentially restricts the availability of other nutrients or sources of carbon. A similar method was cited by other studies on the bioremediation of organophosphates, carbamates and their derivative, the pesticide Phenylpyrazole.

After enrichment, different bacterial colonies were obtained upon sub-culturing on LB agar, including distinctively pigmented orange colonies. Colored bacterial colonies, specifically those producing carotenoid or flexirubin-like pigments, have been associated more often with stress tolerance and ecological competitiveness. Pigmentation protects bacterial cells against oxidative stress, UV radiation and toxic chemicals, which may confer an adaptive benefit in pesticide-polluted soils. Many pesticide-degrading genera reported in literature, like Pseudomonas, Sphingomonas, Micrococcus, Flavobacterium and Rhodococcus, produce colored colonies and harbor enzymatic machinery involved in pesticide degradation.

This degradation has earlier been associated with bacterial enzymes: carbofuran hydrolase, esterases, and monooxygenases, all catalyzing the breakdown of a carbamate group into less toxic intermediates. Degradation of fipronil reportedly occurs by reductive dehalogenation, oxidation, and hydrolysis pathways mediated by soil bacteria. The appearance and persistence of bacterial growth in pesticide-amended MSM strongly indicates the presence of functional metabolic pathways which allow partial or complete transformation of these compounds.

The use of indigenous strains holds considerable advantages over exogenous microbial inoculants, since native microorganisms are already adapted to the local soil conditions, temperature, pH, and competing microbial communities. This increases their survival, activity, and long-term effectiveness when applied for in-situ bioremediation of contaminated farmlands.

Future Perspectives

To further characterize these strains, future studies need to be undertaken. Hence, through metagenome studies carried out on the cultures and original soil samples, detailed insights into the microbial species and genes for pesticide breakdown are expected. Shotgun metagenomics approaches are capable of identifying catabolic genes for pesticide breakdown.

Overall, the isolation of pesticide-tolerant bacterial colonies reflects an important preliminary step toward the development and formulation of a sustainable approach for the bioremediation of pesticide contamination, especially within the scope and boundaries of microbiological science and its associated advances within biotechnology and genomics. Classical microbiology and modern molecular approaches have enormous potential for combating pesticide contamination within the agricultural environment.

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