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Analytical Methods for Extraction, Determination and Degradation of Diazinon in Soil Samples

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ABSTRACT

Diazinon is an organophosphorus insecticide that was widely used in agriculture to control pests on crops. It acts as an acetylcholinesterase inhibitor, which means that it interferes with the normal functioning of the nervous system of insects, leading to their death. Diazinon can also have an impact on human health and the environment, as it can contaminate water and soil and pose a risk to non-target species, including humans and animals. This review paper shows the progress made in the last years in analytical methods applied for the purpose of extraction, detection and degradation of Diazinon as an important environmental pollutant. A variety of sampling and analytical methods have been developed to measure diazinon and its metabolites in different media. The most popular methods for the identification and analysis of Diazinon are liquid and gas chromatography, liquid-liquid extraction, and solid-phase extraction (SPE). The focus of this review is on the identification, measurement, and elimination of diazinon as a major soil pollutant. It begins with a discussion of analytical techniques, followed by an examination of methods for removing diazinon from soil.

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INTRODUCTION

Ensuring the protection of the environment and human health from exposure to persistent organic pollutants is a key priority in developed countries today. Among these pollutants, pesticides hold a crucial position as they are highly toxic and extensively used in agriculture, resulting in approximately 220,000 deaths worldwide each year. Therefore, the development of rapid, simple, and sensitive field methods for detecting pesticides is essential. (Richter et al., 2003). One class of widely used pesticides is organophosphorus compounds (OPs), that are characterized by the presence of thiophosphoryl functional groups (P=S)(Nemati et al., 2013). Organophosphorus pesticides (OPs) were presented in the mid-1960 to supplant the organochlorines to control pests, assuming they display tall harmfulness and less determination (Hamad, 2020; Liu et al., 2019; Zhao et al., 2020). But due to the tall worldwide utilization of organophosphate compounds – approximately 45% of the overall pesticides – the toxicity against non-target life forms like winged creatures, angle, and well-evolved creatures expanded (Aswathi et al., 2019; Shabbir et al., 2018).

One of the frequently used organophosphorus insecticides in agriculture as a soil

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and leaf insecticide is Diazinon (O,O′-diethyl-O′-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate) that works by inhibiting acetylcholinesterase in insects and can have an impact on the human nervous system (Chambers et al., 1992 and Racke 1992, Cao et al., 2018; Glinski et al., 2018). Natural buildups of diazinon can cause hurt to non-target life forms through the discuss, water, soil, and food chain (Wu et al., 2021). The degradation of diazinon can be influenced by factors such as pH and temperature (Mansour et al. 1999), and may happen through either chemical or biological means. However, the relative extent of these processes in different environmental conditions is not fully understood. Volatility of diazinon from soil is minimal, with a tropospheric half-life of 1.5 hours. The movement of diazinon in soil is influenced by organic matter and calcium carbonate, with a moderate mobility due to its K(oc) value of 500. The main factor in diazinon degradation in soil is biological processes (Aggarwal et al., 2013).

Diazinon is toxic to humans and animals if ingested, inhaled, or absorbed through the skin. It can cause symptoms ranging from mild to severe, such as headache, dizziness, nausea, vomiting, abdominal cramps, and diarrhea. In severe cases, it can lead to muscle weakness, breathing difficulties, seizures, and even death. Chronic exposure to low levels of diazinon can lead to neurological and reproductive effects. it is first registered in the United States in 1956 (Kendall et al., 1993 and NPIC, 2003; Khudhur and Sarmamy, 2019).

Diazinon is a clear, colorless to yellowish liquid with a characteristic odor. It is soluble in water and volatile, meaning it can easily evaporate into the air. Diazinon is toxic to a wide range of insects, but it is also harmful to beneficial insects, such as honeybees, and birds. It is effective against adult and juvenile forms of flying insects, crawling insects, and spiders. Due to its toxic effects on non-target organisms and persistence in the environment, diazinon has been banned or restricted in many countries, including the United States (Tang et al., 2009).

Diazinon is available as a dust, granules, seed dressings, wettable powder and emulsifiable solution. Following the application of diazinon, it is frequently detected in the adjacent soil, surface waters, and plant surfaces. On a global scale, >2 million tones of pesticides are being used to control pests, weeds, and insects (Ore et al., 2023). Despite the positive aspect of pesticide application in increasing crop productivity and significantly reducing vector-borne diseases, their unregulated and indiscriminate use has prompted severe concerns about the environment in general and human and animal health in particular (Ashraf Dar et al., 2023).

Diazinon is recognized as a potential insect control solution for various crops, vegetables, and fruits, out of the 41 commonly used organophosphates (OPs). (Hamad, 2020; Zhao et al., 2020). Oxidative harm can be caused by diazinon through free radical era, peroxidation of lipids and DNA fracture. Diazinon can moreover harm the liver, kidney and cause serious histopathological harms (Zhao et al., 2020). Agreeing to the World Wellbeing Organization and the Environmental Assurance Office, the reasonable concentration of diazinon in watery media is less than 9×10^{-6} mg/l (Hamad, 2020).

Soil is a crucial component in the fate of diazinon, as it can either absorb, degrade, or leach the pesticide away from the application site. Overall, soil is a vital component of the earth's ecosystem and plays a crucial role in supporting human life and sustainable development (Mohammadi Aria et al., 2022). Soil provides the growing medium for crops, allowing them to take root, absorb nutrients and water, and grow. Also, Soil is home to a diverse community of living organisms, including bacteria, fungi, invertebrates, and plants. These organisms support the food chain and play a critical role in maintaining biodiversity and ecosystem health. Additionally, Soil filters and purifies water, reducing the risk of water-borne diseases and providing clean drinking water for communities. Therefore, it is crucial to accurately determine the presence of pesticides at trace levels in soil. The measurement of the pesticide residues in soil must be performed using precise, reproducible procedures and reliable, highly sensitive detection techniques. To date, a variety of extraction methods have been utilized to analyze pesticides including soxhlet (Đurović-Pejčev, 2019; Rashid et al. 2010), solid phase extraction (Saraji et al. 2013; Diaz-Cruz and Barcelo, 2006; Dehghan Abkenar et al., 2014), supercritical fluid extraction (Kreuzig, Koinecke, and Bahadir 2000), liquid–liquid extraction (Goncalves and Alpendurada 2005), Pressurized liquid extraction (PLE)(Masia et al., 2015; Diaz-Cruz and Barcelo, 2006), solid-phase microextraction (SPME)(Bagheri 2018; Yamini et al., 2017).

The primary means of degradation for diazinon in water and soil is chemical hydrolysis, which results in the formation of 2-isopropyl-6-methyl-4-pyrimidinol (IMP) and diethyl thiophosphate (DETP) (Gunner and Zuckerman, 1968, the Sethunathan and Yoshida, 1969, Bavcon et al., 2003, Sanchez et al., 2004, Karpouzas and Singh, 2006). Diazinon breaks down quickly in acidic conditions, but is relatively stable at neutral and alkaline conditions (Gomaa et al., 1969, Faust and Gomaa, 1972). The pKa of diazinon has been determined to be around 2.4 (Ku et al., 1998) and the kinetics of its hydrolysis follows a pseudo first-order reaction at a fixed pH (Ku et al., 1998, Mansour et al., 1999). Numerous bacteria species have been found to use diazinon as their sole carbon source, including *Flavobacterium* sp. (Adhya et al., 1981, Forrest et al., 1981), *Pseudomonas* sp. (Adhya et al., 1981), and *Arthrobacter* sp. (Ohshiro et al., 1996). Additionally, the simultaneous action of *Arthrobacter* sp. and *Streptomyces* sp. has been found to enhance diazinon degradation (Gunner and Zuckerman, 1968). The enzymes responsible for hydrolysis are constitutive and capable of breaking down a broad range of substrates, including organophosphate hydrolases (OPH) or phosphotriesterases, which target P–O alkyl and P–O aryl bonds of organophosphates (Adhya et al., 1981, Forrest et al., 1981, Abd-Alla, 1994, Singh et al., 1999) or other groups of organophosphates (Ohshiro et al., 1996). The rate of hydrolysis is faster in aerobic conditions compared to anaerobic conditions. The degradation of diazinon by microbes is facilitated by the presence of organic carbon sources like glucose and alcohols (Sethunathan and Yoshida, 1973; Drufovka et al., 2008).

Extraction and Determination of Diazinon in Soil

Due to the extensive utilization of pesticides and their detrimental effects on human health, it

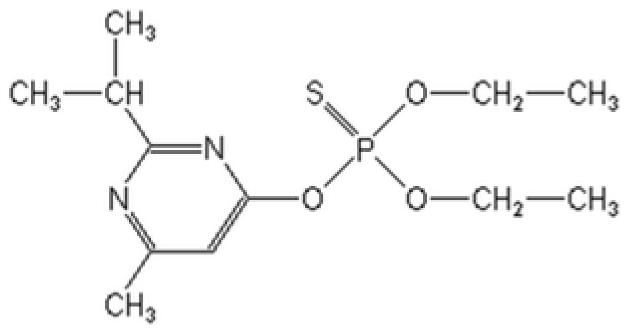

Fig. 1. Molecular structure of Diazinon [Wu et al., 2021]

Table 1. Physical and chemical properties of Diazinon

Description	Properties
Molecular formula	$C_{12}H_{21}N_2O_3PS$
Molar mass(g/mole)	304.3
Density	1.27 g/cm³ at 20°C
Toxicity	UN Hazard Class: 6.1
Chemical family	Organophosphate
Water Solubility (mg/L)	60
pKa	2.4

becomes imperative to closely monitor the accumulation of these substances in the environment, ecosystems, and food sources. This is achieved by conducting precise measurements of their concentration in tangible samples, such as soil. There are several methods available for the determination of diazinon in soil. These methods involve extracting diazinon from the soil matrix, purifying it, and then measuring its concentration. The choice of method for diazinon determination in soil depends on various factors, such as the required sensitivity, available equipment, and the intended use of the results. It is important to follow established protocols and to ensure that the results are accurate, reliable, and properly interpreted.

Sa´nchez et al in 2003 developed a HPLC methods for determining diazinon and fenitrothion, organophosphorus pesticides, in environmental water and soil samples. A simple and fast sample preparation process using solid-phase extraction is developed for water samples. For soil samples, the proposed procedure includes a 10-minute ultrasonic extraction of the target compounds from 20 g of soil with 20 mL of acetonitrile, followed by centrifugation, filtration, and concentration of the supernatant using an SC110H Speed Vac Plus concentrator to remove the solvents. The quantification of diazinon and fenitrothion is done through UV photodiode detection at 245 and 267 nm, respectively (Sánchez et al., 2003).

Also, in another work in 2003, Richter et al reported the determination of pesticides including Diazinon in soil using continuous subcritical water extraction and gas chromatography–mass spectrometry. They used a temperature-controlled laboratory aluminum furnace to perform a subcritical water discharge system in which a pre-radiator and extraction cell were placed. The accompanying factors were considered and controlled the tension at about 1200 p.s.i.: extraction temperature, static and dynamic extraction hours and water flow rate (1 p.s.i. = 6894.76 Pa). As the temperature moves towards quantitative extraction near 300°C, the extraction efficiency of pesticides increases. After interaction extraction, analytes were quantitatively transferred to 5 mL of dichloromethane before confirmation by GC-MS. The results show that under the optimized conditions, most of the analytes are quantitatively extracted in 90 min with recoveries very similar to the standard Soxhlet extraction system (Richter et al., 2003).

A method for determining diazinon in agricultural soil samples using pressurized liquid extraction (PLE) and solid-phase extraction (SPE) combined with gas chromatography-Mass Spectrometry (GC-MS) was developed in 2006. This method was optimized for efficiency and cost-effectiveness by using PLE extraction on spiked soil samples. The method was then applied to soils fertilized with sludge from urban wastewater treatment plants near Barcelona, Spain, and to a representative sludge sample used as fertilizer (Diaz-Cruz and Barcelo, 2006).

A 2007 report detailed an optimized method for determining 6 representative organophosphorus pesticides including diazinon in agricultural soil using microwave-assisted extraction with a water-methanol modified mixture and GC-FPD (gas chromatography-flame photometric detection). Optimization was achieved through two steps: first by experimenting and using principal component analysis, where recovery using water-methanol, and second by adding KH_2PO_4 to the extracting solution, resulting in significantly increased recoveries. Under optimized conditions, pesticide recovery from various soils was over 73% (Bazmi et al., 2016).

In another work in 2010 by El-Saeid et al a screening multi residues method based on the Microwave-Assisted Extraction(MAE) technique has been optimized using soil samples. This method was used to extract 12 pesticides including Diazinon and then the residues in the extracts were analyzed by gas chromatography- Mass spectroscopy(GC-MS). Results of the method were compared with traditional Soxhlet method for soil samples and indicated that the MAE had advantages resulting from the used of a low volume of organic solvent, an unnecessary clean up step and good efficiency to extract different groups of pesticides in soil in 20 min. Diazinon was recovered in good yields and Minimum Detection Limit (MDL) 0.004 mg Kg^{-1} in soil (El-Saeid et al., 2010; Ghali et al., 2006).

In a report in 2009 by Asensio-Ramos et al, a cost-effective and simple method using multi-walled carbon nanotubes (MWCNTs) as solid-phase extraction stationary phases is proposed for the determination of seven organophosphorus pesticides, including diazinon, in different soil samples (forest, ornamental, and agricultural) using gas chromatography with nitrogen phosphorus detection. The soil samples are first extracted using ultrasonic extraction with methanol/acetonitrile, and the evaporated extract is passed through 100 mg of MWCNTs (10-15 nm in outer diameter, 2-6 nm in inner diameter, and 0.1-10 μm in length). The elution is carried out with dichloromethane. The method is validated for linearity, precision, recovery, accuracy, and selectivity, with matrix-matched calibration performed for each type of soil due to statistical differences found between the calibration curves in pure solvent and reconstituted soil extract for most of the pesticides (Asensio-Ramos et al., 2009).

According to a study by Ana Masia et al. (2015), two methods of extracting pesticides from soils were evaluated. These methods, Pressurized Liquid Extraction (PLE) and Quick, Easy, Cheap, Effective, Rugged, and Safe (QuEChERS) extraction, were studied for the instantaneous detection of 50 pesticides including Diazinon in sediment, soil, and sewage sludge. During the development of QuEChERS, various buffers and dispersive solid-phase extraction (dSPE) sorbents were tested. The PLE method was evaluated for various parameters that could impact extraction efficiency, such as the type of organic solvent, sample size, cell size, temperature, pressure, duration of static time and number of cycles as well as the sorbent used for online cleaning. The performance of PLE and QuEChERS was then compared based on their recovery rates (33-89% for PLE and 25-120% for QuEChERS), the number of pesticides for which recovery was in the range of 80-100% (up to 13 for PLE and up to 35 for QuEChERS), and the cost of the methods. The QuEChERS procedure was found to be faster, more affordable, and easier to perform (Masia et al., 2015). N. Pajooheshpour in 2018 used a new Enzymeless electrochemical sensors based on Au-Pt nanoclusters-graphene nanoribonns to develop a rapid, selective, and sensitive electrochemical sensor for diazinon determination in a voltammetric determination. The constructed electrode was employed for the determination of diazinon in some real samples with complex matrices such as soil (Pajooheshpour et al., 2018).

In a report by Ng et al. in 1999, Headspace solid-phase microextraction (SPME) has been used for the analysis of common organophosphorus pesticides in soil. solid phase microextraction (SPME) has demonstrated unquestionable advantages as an efficient sample preparation technique for several applications over traditional methods in more than the last two decades. This technique offers numerous benefits such as minimum solvent use, integration of sampling and sample preparation steps, high sensitivity, simple operation, low cost, easy coupling with chromatographic techniques, and the possibility of an on-line analytical procedure (Dehghan Abkenar et al., 2006, 2008). In this report, To optimize extraction efficiency, various factors such as adsorption-time, sampling temperature and matrix modification were taken into consideration. The method developed was capable of detecting Diazinon limits of 28.6 ng/g in humic soil using gas chromatography-flame ionization detector (GC-FID), and 14.3 ng/g by analyzing the extracted sample with gas chromatography/mass spectrometric detector (GC/MS). Precision was found to be satisfactory, with approximately 6.5% RSD for sandy soil and 15% for humic material. Additionally, headspace solid-phase microextraction (SPME) was compared to aqueous extraction of soil followed by SPME (LE-SPME). The headspace SPME was found to be comparable in terms of extraction recovery to liquid-liquid extraction of soil followed by SPME, but with less background interference. Moreover, the technique's non-destructive nature allows for further laboratory analysis of the samples after headspace SPME has been performed, making it highly advantageous (Ng et al., 1999).

In 2018, Bagheri et al. developed a nanocomposite consisting of a zinc-based metal-organic framework and polyethersulfone (TMU-4/PES) that could be used as a coating for headspace solid-phase microextraction (HS-SPME) of organophosphorus pesticides, including diazinon. The nanocomposite coating was deposited on a stainless steel wire using a single-phase inversion method. It exhibited excellent performance for HS-SPME of organophosphorus pesticides from environmental water and soil samples, which were subsequently quantified by gas chromatography with a nitrogen-phosphorus detector. The coating was simple to prepare, stable, and reusable for up to 100 extractions/desorption cycles. The repeatability and fiber-to-fiber reproducibility were found to be 6.5% and 8.7%, respectively. The technique was used for the trace determination of organophosphorus pesticides in spiked water and soil samples, with superior recovery (88-108%) and satisfactory reproducibility (5.9-10.1%) (Bagheri et al., 2018).

In another work, Rahmani and Aibaghi reported a rapid, efficient, and sensitive dispersive solid-phase microextraction method joined with ion mobility spectrometry for the concurrent determination of bendiocarb, butachlor, and diazinon developed by zinc sulfide/sulfur/sulfur-doped reduced graphene oxide (ZnS/S/S-RGO) nanocomposites. ZnS/S/S-RGO three-component nanocomposites were synthesized through a single-step solvothermal procedure under the best conditions, linear ranges were reached 0.5–100 ng mL^{-1} with detection limits of 0.27±0.02 ng mL^{-1} for diazinon, respectively. The method was employed for the ultra-trace determination of pesticides in water, rice, and soil samples with acceptable recovery values within the range 96.6±4.8–104.4±6.4% (Rahmani & Aibaghi, 2022).

In a report in 2019 by Đurović-Pejčev compared three soil sample preparation methods: QuEChERS (quick, easy, cheap, effective, rugged, and safe), traditional solid-liquid extraction (SLE), and Soxhlet extraction. Detection and quantification of pesticides were carried out using gas chromatography-mass spectrometry (GC-MS). Generally, Traditional soil sample preparation methods like SLE and Soxhlet extraction are lengthy, costly, and require a lot of organic solvents. They also have many steps, leading to potential loss of analyte. To overcome these limitations, the focus has shifted towards simpler, faster, and more affordable methods. QuEChERS, developed by Stassiades et al. has emerged as a popular technique for determining pesticide residues in various sample matrixes. It reduces complicated steps, costs less per sample, requires less solvents and glassware, and is quicker and less demanding. Despite widespread use for multiclass pesticide determination in foodstuffs like vegetables, fruits, cereals, and honey, QuEChERS has been less commonly applied to soil. However, as Pszczolińska and Michel (2016) noted, it has strong extraction and cleanup capabilities for pesticide determination in complex soil samples (Đurović-Pejčev et al., 2019).

Also, Salama et al in 2020 worked on a Quick, Easy, Cheap, Effective, Rugged and Safe method (QuEChERS) method to extract 30 pesticides which are common in Egypt in soil and water. They used Experimental Design expert 7.1 to optimize conditions for better recoveries. Determination of these pesticides including Diazinon were performed with GC-MS. Total analysis time was 36 min with 1 ml injection volume. The limit of quantification (LOQ) was ranged between 4.59 ng/ml, and 15.91 ng/ml for all pesticides. Most standard deviations were in the range between 0.41 and 1.41 indicating acceptable accuracy. The confirmed method was used to Egyptian soil and drainage water samples from special places. (Salama et al., 2020).

In another work, the impact of diazinon insecticide on three soil orders (Entisols, Vertisols, and Inceptisols) at two soil moisture levels (50% and 100% of field capacity) was investigated. Soil samples were extracted using ultrasonic agitation with acetonitrile,. Diazinon was analyzed using high performance liquid chromatography (HPLC) with a reversed-phase C-18 column and UV detector. Results showed that diazinon residues were found to be above the established maximum residue limit (MRL) 24 hours after application. However, no residue was detected in the treated soils during subsequent sample collections, suggesting that the diazinon had degraded completely. This outcome could be attributed to factors such as the properties of diazinon, environmental conditions, microbial activity, and soil characteristics (Khudhur and Sarmamy, 2019).

Recently, Mohammadi Aria et al in 2022 reported using ion mobility spectrometry (IMS) for detecting and measuring diazinon in soil samples. They optimized a solid-liquid extraction process and applied it to three different soils. The recovery values obtained ranged from 95% to 104%. The researchers suggested that the method is efficient enough for routine use in determining diazinon in soil samples. IMS is a new alternative for analyzing low levels of various compounds, including drugs, pesticides, and chemical warfare agents. It works by vaporizing, ionizing, and separating the sample based on the mobility of ionic species in the gas phase. This technique offers many advantages, including fast response, cost-effectiveness, simple instrumentation, ease of maintenance, reliable performance, high portability, and high sensitivity (detection limits ~ ppb). Hence, IMS shows great potential as an alternative method for analyzing pesticides in different environmental matrices such as soil (Mohammadi Aria et al., 2022).

Kumaran and Morita in 1995 offered a butyrylcholinesterase biosensor, according the principle of enzyme inactivation, to find out some organophosphorus pesticides (Fenitrothion, Diazinon, Parathion ethyl, Mevinphos and Heptenophos) in soil extracts. The enzyme was immobilized on pre-activated transfer membranes, which were physically connected to the sensitive ends of glass pH electrodes. make contact with the enzyme with pesticide samples consequences in specific inhibition of enzyme activity. Sensor calibration was made by correlating the inhibition of enzyme activity with changing concentrations of pesticide compounds in a buffer solution. Also a simple method was designed to extract ORP pesticides from spiked soil samples using a mixture of dichloromethane and acetone as the extraction solvent mixture (Kumaran and Morita, 1995).

Removal Techniques

The most effective and practical treatment for pollutants or contamination should aim to minimize pollution discharge and environmental impacts while being strong and economically viable. (Fan et al., 2009). There are several articles available for the removal of diazinon from soil. For instance, in a recent study, a novel approach using a deep eutectic solvent embedded in melamine sponge (DES–MS) was investigated for the removal of organic pollutants from water and soil samples. In this work, five organophosphorus pesticides (OPPs), including diazinon (DIZ), were targeted. First, DESs were simply set from tetrabutylammonium bromide (TBABr) and different fatty acids. The synthesized DESs were then loaded into the sponge before being utilized for the removal of the studied pollutants. After the removal, the residual OPPs was determined by high performance liquid chromatography. The method was easy, fast, environmentally friendly and effective with the removal efficiency higher than 70% for different samples (Gissawong et al., 2020).

Diverse techniques have been utilized to remove pesticides such as adsorption, oxidation and bioremediation. These techniques have their own advantages and disadvantages. However, adsorption remains a widely accepted technique due to its simplicity and efficiency in handling many types of pollutants. The key factor in adsorption is the selection of an appropriate adsorbent material (Gissawong et al., 2020; Pandit and Basu, 2004).

Adsorption

Adsorption has validated to be an efficient approach for removing organic and inorganic contaminants in water. It is worthwhile, sustainable, easy to function, and produces no intermediate (Adeola, et al., 2022; Bayode, et al., 2020; Bayode, et al., 2018). The widespread benefits supplied with the aid of adsorption consist of the benefit of operation and regeneration, among others (Adebiyi et al., 2021; Adeola et al., 2022).

Ban et al. in 2022 prepared biochar from raw and pretreated biomass using a carbonization process. Biochar derived from pretreated biomass had an aromatic and graphitized structure, and functional groups were observed on the surface. The specific surface area was higher for biochar obtained from pretreated biomass than biochar derived from raw biomass. The biochar obtained from pretreated biomass contained a greater number of micro pores than biochar derived from raw biomass. The diazinon removal rate was the highest for biochar that was obtained from pretreated biomass when 10% of the biochar was added to the soil. Biochar is an effective adsorbent that is produced by pyrolysis or the thermochemical conversion of various types of biomass. Pyrolysis is conducted under inert nitrogen conditions with a limited supply of oxygen for more than 1 h at temperatures ranging from 300 to 800°C (Ban et al., 2022).

Hassan et al. in 2017 proposed adsorption and photocatalytic degradation as a method for the detoxification of diazinon. Activated carbon (AC) was chemically prepared from flamboyant pods and modified with iron (Fe-AC) to be used as a solid adsorbent for diazinon. TiO_2 and TiO_2-AC photocatalysts for the degradation of diazinon were prepared using the sol-gel method. The effects of pH, time, adsorbent dosage, and concentration on adsorption of diazinon on AC and Fe-AC were investigated. The results showed that the adsorption capacity of Fe-AC was three times higher than that of AC. In addition, the adsorption process followed both pseudo-first- and pseudo-second-order equations. The photocatalytic degradation efficiency of diazinon using TiO_2-AC was found to be higher than that of TiO_2, achieving 95% degradation after 80 minutes compared to 55% for TiO_2 (Hassan et al., 2017).

Photocatalysis

Photocatalysis is an event that occurs on the surface of a material as photocatalyst that has been irradiated with light of a particular wavelength. An electron-hole pair is produced upon exposure of the photocatalyst to light (Alegbeleye, et al., 2022). The importance of this process is reflected in the photocatalyst's ability to create an oxidation and reduction environment at the same time, and this has found wide applications in air purification and wastewater treatment (Ameta, et al., 2018). Although photocatalysis is considered to be a more advantageous technology than adsorption, the corrosion of photocatalysts in aqueous media under light irradiation has been a significant challenge. This has led to the development of more stable photocatalysts that are less prone to corrosion. (Ore et al., 2023). For instance Hossaini and his colleagues evaluated the preparation and characterization of an efficient TiO_2-based photocatalyst doped with a mixture of metal (Fe) and non-metal (N, S, F) elements as a novel catalyst for degradation of diazinon model pesticide using (UV-light emitting diodes) LED-activated photocatalysis (Hossaini et al., 2014).

Bioremediation

The procedure that involves the use of microorganisms, plants, and plant enzymes in the cleaning of environmental pollutants is called Bioremediation (Adebiyi, et al., 2021). The dynamic substances of pesticides deliver contamination in soil environment, affecting microorganisms living there. Hence, they may also interfere with the right arrangement of biochemical pathways in soil biogeochemical cycles (Verma et al., 2014). A few physicochemical strategies can be connected to disseminate pesticides starting from sullied soil and water (Hamad, 2020). In any case, most of them are costly, not one or the other eco-friendly nor down to earth; they too posture some disadvantages which require bioremediation (Hamad, 2020; Shabbir et al., 2018). Since of the broad request for the advancement of unused advances to guarantee security, viability, and conservative clean-up and detoxification of these poisons, bioremediation approaches have pulled in impressive consideration. Bioremediation utilizes certain microorganisms to break down dangerous manufactured chemicals within the environment (Shabbir et al., 2018). In this manner, numerous sorts of investigate have centered on the organic expulsion of pesticides. Remediation of agrarian soil remains an unsolved biological issue which means poison expulsion isn't appropriately performed due to a need of commonsense approaches. Evacuation instruments have been made utilizing different physical, chemical and organic strategies

(Aparicio et al., 2022). The microbial community has been included especially owing to their various preferences. Plant species are too been utilized along for mobilizing and retaining toxins. Combined therapeutic measures have been performed utilizing organisms and plants (Bhat et al., 2022). The combined mutualism impact of plant species and organisms increments the bioavailability of poisons for corruption and evacuation.

during the last decade, microorganisms have played a vital function in the degradation of various organic contaminants in the environments and use them as the main source of energy and carbon for their growth (Zhang, et al., 2021; Bhatt, et al., 2021). Different microorganisms like bacteria, fungi, and algae that break down organophosphate pesticides have been removed from soil and characterized in recent years.

Bacteria, fungi, actinomycetes, and algae that can remove diazinon were obtained by enrichment cultures (Cycoń et al., 2009; Pourbabaee et al., 2018; Hamad, 2020).

Various microorganisms have been recognized and utilized as a diazinon degrader, counting a few microscopic organisms such as *Streptomyces* sp. (Briceño et al., 2016), *Stenotrophomonas* sp. (Deng et al., 2015), *Pseudomonas* sp. (Mahiudddin et al., 2014), and *Ralstonia* sp. (Wang and Liu, 2016) and contagious strains counting *Aspergillus* sp. and *Penicillium* sp. (Alvarenga et al.,2014; Tian et al., 2016) which have illustrated a incredible potential for the corruption of organophosphate pesticides. The reason why these microorganisms can successfully corrupt diazinon lies within the different chemicals contained in their bodies. These chemicals have tall protein movement and a assortment of hydrolysis and oxidation capacities, which can turn the toxins into brief chain items with moo harmfulness. Be that as it may, the pH, temperature, and moo solidness properties of these chemicals restrain their utilize in mechanical applications (Bhatt et al., 2020b; Mishra et al., 2021). At show, individuals utilize the immobilization innovation of chemicals to progress the warm steadiness, decrease the hindrance of the item, and overcome the common trouble of solvency. In any case, analysts don't have the total framework required to characterize the successful corrupting proteins contained in microorganisms. This increments the trouble of consequent thinks about on the debasement of diazinon (Wu et al., 2021). Analysts have utilized enhancement methods to explore for microorganisms that can be utilized to mineralize diazinon to diminish the concentrations of diazinon in soil rural wastewater release frameworks, seawater frameworks, and overwhelming industry (Briceño et al., 2015; Wang and Liu, 2016). In any case, as it were a little number of microorganisms have been separated and distinguished.

Recently, Mostafa et al. isolated biodegradable soil fungi that are able of metabolizing diazinon. In order to identify the level of pesticide pollution in the soil samples, the collected samples were examined for the presence of diazinon. The biodegradation efficiency and tolerance of the isolated fungal strains to different concentrations of diazinon pesticide were investigated using solid and liquid mediums, employing food poisoning techniques. To confirm the biodegradation efficiency, GC-MS analysis was performed on the control and treated flasks to quantify residual diazinon after biodegradation (Mostafa et al., 2022).

Three bacterial strains viz. *Serratia liquefaciens*, *Serratia marcescens* and *Pseudomonas* sp. were detailed to corrupt diazinon with noteworthy potential in soil by Cycoń et al. (2009). Segregates were developed in methylotrophic particular mineral salt medium (MSM) in conjunction with pesticide diazinon as a source of carbon substrate (50 mg L^{-1}). Almost 80–92% of pesticide was corrupted by bacterium and their consortia inside 14 days of the introductory dosage of bug spray provided. A solid relationship was gotten between microbial exercises with chemical handle amid corruption of diazinon. In addition, these powerful bacterial strains can be used in microbial remediation of diazinon wealthy soils (Kumar et al., 2021).

Wang and Liu (2016) depicted the pesticide corrupting capacity of *Ralstonia* sp. DI-3 separated from an agrarian soil. The DI-3 strain was found to corrupt diazinon, an organophosphate bug spray recognized within the environment. A concentration of 100

Table 2. Different microorganisms utilized for the degradation of various organophosphate pesticides in soil.

Microbes	Strain type	References
Pseudomonas sp.	Bacterium	(Cycoń et al., 2009)
Serratia marcescens	Bacterium	(Hussaini et al., 2013)
Serratia marcescence DI101	Bacterium	(Abo-Amer, 2011)
Arthrobacter sp. *Mycobacterium* sp.	Bacterium	(Seo et al., 2007)
Flavobacterium sp. ATCC 27551	Bacterium	(Mulbry and Karns, 1989)
Stenotrophomonas maltophilia	Bacterium	(Pourbabaee et al., 2018)
Bacillus amyloliquefaciens YP6	Bacterium	(Meng et al., 2019)
Pseudomonas citronellolis strain ADA-23B	Bacterium	(Góngora-Echeverría et al., 2020)
Pseudomonas putida D3	Bacterium	(Hassanshahian, 2016)
Aspergillus niger MK640786	Fungus	(Hamad, 2020)
Rhodotorula glutinis and *Rhodotorula rubra*	Fungus	(Bempelou et al., 2013)
Serratia marcescens	Bacterium	(Cycoń et al., 2009)
Serratia liquefaciens	Bacterium	(Cycoń et al., 2009)
Streptomyces sp. AC1-6., Streptomyces sp. ISP4	Bacterium	(Briceño et al., 2015)
Bacterium Enterobacter B-14	Bacterium	(Singh et al., 2004)
Ralstonia sp. DI-3	Bacterium	(Wang and Liu, 2016)
Pseudomonas peli, Burkholderia caryophylli, and Brevundimonas diminuta	Bacterium	Mahiudddin et al., 2014)
Saccharomyces cerevisiae	Fungus	(Ehrampoush et al., 2017)

mg L^{-1} diazinon was expended inside 2-3 days in broth culture and a follow sum of co-substrate may upgrade the debasement capacity into the media.

CONCLUSIONS

The global population is currently grappling with a public health risk arising from pervasive pesticide contamination in agricultural regions, particularly in developing nations. Pesticide poisoning is a grave concern, leading to the loss of approximately 220,000 lives annually worldwide. In order to ensure that farmers and consumers are aware of the dangers posed by pesticides, the development of quick, effortless, and sensitive field methods for detecting these chemicals is crucial.

Organophosphorus substances (OPs), commonly used as pesticides, contain thiophosphoryl functional groups (P=S) that make them potent inhibitors of the acetylcholinesterase enzyme. This inhibition has the potential to lead to the accumulation of acetylcholine at nerve endings in the peripheral or central nervous systems, posing serious health risks.

The fate of diazinon, in particular, is greatly influenced by the characteristics of the soil it is applied to. Soil can absorb, degrade, or leach the pesticide from the application site. Soil plays a critical role in sustaining human life and promoting sustainable development. It serves as a vital growing medium for crops, supports a diverse ecosystem of living organisms, and acts as a natural water purifier. Given that pesticides like diazinon can transfer from soil to food, it becomes essential to detect their presence in soil at trace levels. Additionally, monitoring the content of diazinon is necessary to ensure food safety and protect consumer health.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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