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# Organophosphorus pesticides: reviewing their agricultural-environmental balance, control and remediation
# Pesticidas organofosforados: revisión de su equilibrio agrícola-medioambiental, control y remediación

Z. Gómez Soto [a], C. Ángel Jijón [b], O.A. Acevedo Sandoval [c], E. Cornejo Velázquez [c], M.A. Veloz Rodríguez [a],
R.A. Vázquez García [a,] *

[a] Universidad Autónoma del Estado de Hidalgo - Instituto de Ciencias Básicas e Ingeniería, Área Académica de Ciencias de la Tierra y Materiales, Mineral de la Reforma Carretera Pachuca-Tulancingo Km. 4.5, 42184. Hidalgo, México.
[b] Tecnológico Nacional de México Campus Acapulco, Acapulco de Juárez, Avenida Instituto Tecnológico Km. 6.5, S/N, Col. El Cayaco, C. P. 39905, Guerrero, México.
[c] Universidad Autónoma del Estado de Hidalgo - Instituto de Ciencias Básicas e Ingeniería, Área Académica de Química, Mineral de la Reforma Carretera Pachuca-Tulancingo Km. 4.5, 42184. Hidalgo, México.
[d] Universidad Autónoma del Estado de Hidalgo - Instituto de Ciencias Básicas e Ingeniería, Área Académica de Computación y Electrónica, Mineral de la Reforma Carretera Pachuca-Tulancingo Km. 4.5, 42184. Hidalgo, México.

**Abstract**

Organophosphorus pesticides (OPPs) are compounds derived from phosphoramidic acid, phosphonic acid, or phosphoric acid employed for pest control, especially as insecticides in the production of several commodities. However, for more than 50 years, OPPs have been applied in an unconscionable manner causing adverse effects on human health and environmental quality. In this study, a literature review of OPPs situation between 2021 and 2025 was carried out taking into account research papers, reviews, books, conference proceedings, and other online resources prioritizing toxicological information, legal standards of Maximum Residue Limits (MRLs), removal and bioremediation, as well as techniques for the detection and quantification of OPPs. Some pesticides, such as Malathion, Parathion, Phosmet and Diazinon, are examples of OPPs that continue being used in food production, causing pest resistance and ecological damage. It is important to implement a combination of practices, including the removal, bioremediation, detection and quantification of OPPs, to achieve sustainable development in food production.
*Keywords:* Organophosphate pesticides, bioremediation, quantification, removal, Maximum Residue Limits.

**Resumen**

Los plaguicidas organofosforados (OPPs) son compuestos derivados del ácido fosforamídico, ácido fosfónico o ácido fosfórico que se emplean para el control de plagas, especialmente como insecticidas en la producción de varios productos básicos. Sin embargo, durante más de 50 años, los OPPs se han aplicado de manera irresponsable, causando efectos adversos en la salud humana y la calidad del medio ambiente. En este estudio, se llevó a cabo una revisión bibliográfica de la situación de los OPPs entre 2021 y 2025, teniendo en cuenta artículos de investigación, reseñas, libros, actas de conferencias y otros recursos en línea, dando prioridad a la información toxicológica, las normas legales de límites máximos de residuos (LMR), la eliminación y la biorremediación, así como las técnicas para la detección y cuantificación de los OPPs. Algunos plaguicidas, como el malatión, el paratión, el fosmet y el diazinón, son ejemplos de OPPs que siguen utilizándose en la producción de alimentos, causando resistencia de las plagas y daños ecológicos. Es importante aplicar una combinación de prácticas, que incluyan la eliminación, la biorremediación, la detección y la cuantificación de los OPPs, para lograr un desarrollo sostenible en la producción de alimentos.

*Palabras clave:* Pesticidas organofosforados, biorremediación, cuantificación, remoción, Límites Máximos Residuales.

## 1. Introduction

Pesticides are organic compounds widely used in agriculture to control insect infestations. This category

*Autor para la correspondencia: rosavg@uaeh.edu.mx
**Correo electrónico**: go242872@uaeh.edu.mx (Zianya Gómez Soto), carlos_angel@uaeh.edu.mx (Carlos Ángel Jijón), acevedo@uaeh.edu.mx (Otilio Arturo Acevedo Sandoval), ecornejo@uaeh.edu.mx (Eduardo Cornejo Velázquez), mveloz@uaeh.edu.mx (María Aurora Veloz Rodríguez), rosavg@uaeh.edu.mx (Rosa Angeles Vázquez García)
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includes insecticides such as organophosphorus pesticides (OPPs), which have provided huge benefits to food production by increasing crop yields through pest control or insect control (Fu et al., 2022). However, the excessive and indiscriminate application of OPPs has also generated significant adverse effects on both the environment and human health. Since 1942, over 50,000 products of this kind have been created, serving not only as insecticides but also as acaricides, nematicides, fungicides, and, in severe situations, as chemical warfare agents (Caño et al., 2007).

Given the relevance of organophosphorus compounds in environmental, health, and economic context, it is essential to assess their effects investigate their effects, methods to identify them in various environmental samples, and techniques for their elimination. It is necessary to reduce the influence of these pesticides on humans and the environment (Ajiboye et al., 2022).

In this study, a literature review was carried out to gather the most recent information about OPPs in topics such as chemical characteristics, regulations, toxicology, environmental occurrence, detection techniques, removal and bioremediation to assess the possibility of managing their use instead of eradicating their use in pest control without generating adverse effects on human health and the environment. This approach promotes agri-food safety, as the supply of food demand and product quality largely depend on controlling phytopathogens

The literature review on organophosphorus pesticides, was established with an emphasis on topics such as their use and bioremediation methods, including usage, toxicology, environmental impact, regulations against decomposition, detection, and strategies for reduction. Important databases were utilized, including Scopus, Web of Science, PubMed, and Google Scholar, among others. The search for papers, reviews, books, conference proceedings, and other online resources took place. The keywords used for the search included: "organophosphorus pesticides (OPPs)," "classification of organophosphorus pesticides (OPPs)," "effects of organophosphate pesticides (OPPs) on health and the environment," "bioremediation and removal of organophosphate pesticides (OPPs)," and "quantification and sensing of organophosphorus pesticides (OPPs)," with only articles published between 2021 and 2025 being selected (Gbadamosi et al., 2021).

Relevant information was gathered, including the types of pesticides examined, the results of toxicological assessments, the regulatory framework and application scenarios, the methods used for OPPs detection such as spectroscopy, electrochemical and optical techniques, the strategies for remediation in natural resources as soil and water, emerging strategies in OPPs controlled usage, monitoring in real time and removal or bioremediation practices implementation in crop production to ultimately formulate coherent arguments and conclusions.

## 2. Methodology

## 3. Results and discussion

The majority of organophosphorus pesticides are primarily esters that derive from phosphoramidic acid, or phosphoric acid, combined with aryl or alkyl groups, along with various side chains or leaving groups (Singh & Walker, 2006). These compounds are frequently categorized according to their leaving group into heterocyclic, phenyl, and aliphatic (Sarlak et al., 2021), an example of each group can be observed in Figure 1 the main physicochemical properties are listed in Table 1.

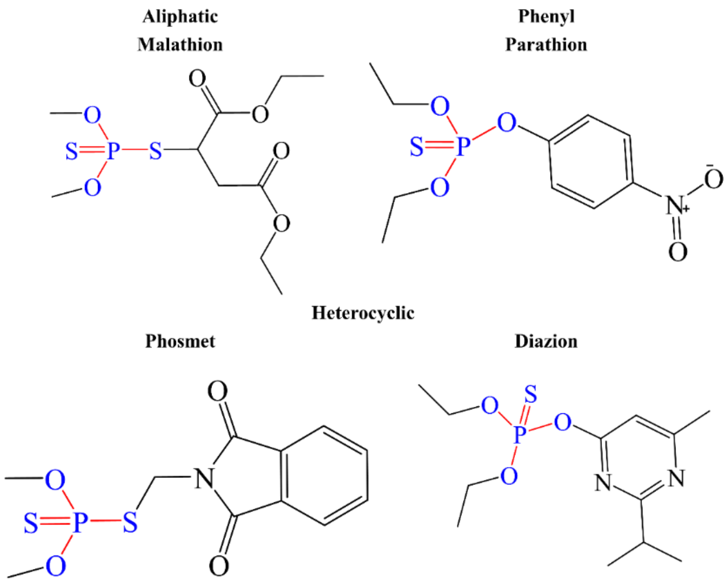


Figure 1. Classification of organophosphorus pesticides

Table 1: Physicochemical properties of Organophosphorus compounds

| Pesticide | MW (g/mol) | Density | Boiling Point | MP (°C) | Solubility |
|---|---|---|---|---|---|
| Malathion | 330.4 | 1.2 **(water = 1)** | 156-157 °C at 0.7 mm Hg | 2.8 | Ethanol, benzene and ethyl ether. In water, 143 mg/L at 20 °C |
| Parathion | 291.26 | 1.26 **(water = 1)** | 375 °C at 760 mm Hg | 6.1 | Alcohols, esters, ethers, ketones, aromatic hydrocarbons, animal & vegetable oils. Water solubility = 11 mg/l @ 20 °C |
| Phosmet | 317.3 | 1.03 g/cmÂ³ | Decomposes below boiling point (EPA, 1998) | 72-72.7 | Dichloromethane, 4-methylpent-3-en-2-one, butanone. In water, 24.4 mg/L at 20 °C |
| Diazinon | 304.35 | 1.1 (water = 1) | 125 °C at 1 mm Hg | < 25 | Common organic solvents, e.g. ethers, alcohols, benzene, toluene, hexane, cyclohexane, dichloromethane, acetone, petroleum oils. |

MW: Molecular Weight, MP: Melting Point (National Center for Biotechnology Information, 2025)

Malathion appears as a liquid that ranges in color from yellow to dark brown and has an odor reminiscent of skunk. It is denser than water. Its freezing temperature is 37 °F. (USCG, 1999). Malathion remains stable in water solutions with a pH of 5. 26. However, it breaks down in environments with a pH lower than 5 or higher than 7. It should not be exposed to temperatures above 55 °C. When it reaches temperatures over 100 °C, it breaks down quickly and can lead to explosions ([a]NCBI, 2025); Parathion is a dark brown to yellowish fluid that has a slight garlic scent. This substance is a phosphate-based insecticide that inhibits cholinesterase and is extremely poisonous through any method of exposure. It can exist as a liquid or in a powdered form where the liquid is incorporated onto a solid carrier (NCBI, 2025); Parathion is a dark brown to yellowish fluid that has a slight garlic scent. This substance is a phosphate-based insecticide that inhibits cholinesterase and is extremely poisonous through any method of exposure. It can exist as a liquid or in a powdered form where the liquid is incorporated onto a solid carrier (NCBI, 2025) and Diazinon is a liquid; varying from light brown to dark brown. It has a tendency to settle in water. Commercial products may include ethanol, xylene, or acetone, with a flash point ranging from 82 to 105 degrees Fahrenheit. Its functions include acting as an agrochemical, serving as an acaricide, inhibiting EC 3. 1. 1. 8 (cholinesterase), functioning as a nematicide, inhibiting EC 3. 1. 1. 7 (acetylcholinesterase), and being classified as a xenobiotic and an environmental pollutant. It belongs to the category of organic thiophosphates and is included among pyrimidines. It is functionally linked to 2-isopropyl-6-methylpyrimidin-4-ol.

The primary function of these substances is to block the enzyme acetylcholinesterase, which disrupts nerve signalling in the organisms that come into contact with them and may lead to both acute and subacute toxicity in insects and mammals, including humans (Ponce et al., 2006). In Table 1, the most important information regarding the OPPs examples, such as distributor, commodity, dose (L/ha), and targets, is shown and some examples are illustrated in Figure 2.

Table 2. Technical information on Organophosphorus pesticides (List of Authorised Products. Strawberry. In compliance with the United States, 2021).

| Pesticide | Distributor | Commodity | Dose (L/ha) | Plague |
|---|---|---|---|---|
| Malathion | Calidad Tridente | Eggplant, onion, pepper, bean, rice, wheat | 0.5-1.0 | *Epitrix spp., Thrips tabaci, Spodoptera exigua,* |
| Parathion | Calidad Tridente | Cotton, tobacco, potato, soybean | 1.0-1.5 | *Frankliniella spp., Aphis gossypii., Anthonomus grandis.* |
| Phosmet | Gowan México | Cotton, apple, potato, blueberry | 1.0-2.0 | *Anthonomus grandis, Cydia pomonella, Phthorimae opercullela, Drosophila suzukii* |
| Diazinon | Sifatec | Blackberry, Broccoli, cucumber, bean, maize, onion, peach, pepper | 1.0-1.5 | *Tetranychus spp., Trialeurodes sp., Lygus spp., Aphis spp., Liriomyza spp.* |

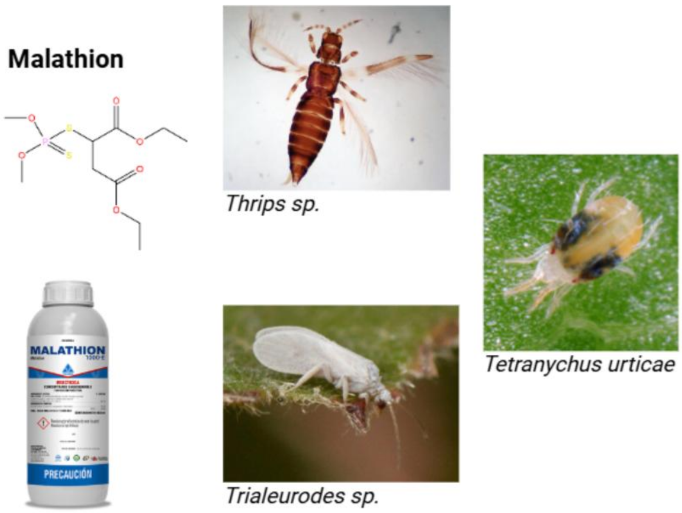


Figure 2. Commercial product and plagues reported in AneBerries

Moreover, another significant challenge in agricultural pest management is insecticide resistance, which occurs when a group of insects acquires the capability to survive levels of poisons that would be deadly to most members of a typical population of that species (Venkatesan et al., 2022). Such is the case of the oriental fruit fly, *Bactrocera dorsalis*, that have emerged with resistance to chemical insecticides, including organophosphorus, neonicotinoid, pyrethroid, and macrolides making this situation a critical point. This emphasizes the importance of ensuring proper and regulated application levels to prevent irrational and unadvised overuse. (Meng et al., 2023).

According to the Codex Alimentarius (2025), the marks that pesticides leave on treated items or those remaining from veterinary medications in animals are referred to as "residues". The levels of residues detected in food should be safe for people consuming it and should be minimized as much as possible. Some Organizations set Maximum Residue Level (MRL) for commodities in which plaguicides were applied such as COFEPRIS in Mexico and

Codex Alimentarius from the Food and Agriculture Organization of the United Nations (FAO). In Table 2, the MRL for Berries and strawberries is listed for each example of OPP in ppm.

As can be observed, Malathion has the highest levels, these are estimated by taking into account the calculous of dietary intake, and it is the most widely used. The lowest levels belong to Diazinon, and its number of commodity applications is the smallest.

Table3. Organophosphorus pesticides MRL for Berries and Strawberry according to COFEPRIS and Codex Alimentarious (Codex Alimentarius, International Food Standards, 2004), Codex Alimentarius), (International Food Standards, 2005), (Codex Alimentarius, International Food Standards 2015), (Codex Alimentarius, International Food Standards, 2015).

| Pesticide | COFEPRIS (ppm) | Codex Alimentarius (mg/kg) |
|---|---|---|
| Malathion | 8 | 10 |
| Parathion | 0.1 | 5 |
| Phosmet | 10 | 3 |
| Diazinon | 0.5 | 0.2 |

*3.1 Toxicity*

The organophosphorus pesticides remain in the environment for a long time under acidic conditions, with a lot of organic matter in the soil, limited light, and cooler temperatures (Bose et al., 2021). The harmfulness of OPPs is influenced by Sulphur and the oxidation state of phosphorus as an acetylcholinesterase (AChE) inhibitor (Chen et al., 2021). The route of exposure might occur through skin absorption from contact with dust that contains these pesticides, or through eating or drinking contaminated food and water (Gbadamosi et al., 2021). Malathion is corrosive to metals such as iron, certain plastics, and coatings (National Centre for Biotechnology Information). Some studies (Table 4) indicate that OPPs cause nerve damage by either adding phosphate groups to acetyl cholinesterase or neuropathy target esterase, or by attaching directly to nicotinic or muscarinic receptors in the nervous system. In addition to causing neurobehavioral changes in people, OPPs can lead to cholinergic crisis, intermediate syndrome, delayed neuropathy induced by OPPs, and chronic neuropsychiatric issues related to organophosphate exposure, all of which depend on the timing and amount of exposure. Monitoring OPPs indicators in bodily fluids helps to lessen or assess the intensity of the effects, enabling prompt management of exposure levels (Ganie et al., 2022). Furthermore, it has been reported that one of the molecular processes accounting for the negative impacts of exposure to organophosphate pesticides is the oxidative stress that promotes an increase in the frequency of processes such as eryptosis and/or haemolysis in red blood cells, leading to a higher vulnerability to clinical conditions like anaemia, dehydration, and chronic kidney disease (Freyre et al., 2021). Other research affirms that OPPs may also possess the potential to cause genetic damage, even at minimal amounts, OPPs have been demonstrated to harm DNA and lead to cell malfunctions. Typical reactions observed in cells subjected to OPPs involve the creation of DNA adducts and injuries, as well as single-strand and double-strand breaks in DNA, along with intra and inter-cross-links between DNA and proteins, leading to various diseases, including cancer, Alzheimer's, and Parkinson's disease (Prathiksha et al., 2023). The uncontrolled proliferation became a significant threat to the ecosystem; thus, measures have been essential to safeguard living beings and the environment from further damage (Singh et al., 2023). Thus, the OPPs employment in crop production has an important role in quality products and the crop yield due to plague control. OPPs control several plagues which represent a serious threat that can result in significant economic losses for the producer, taking in count its adverse effects in human health and environmental quality, institutions have developed the risk dietary evaluation to formulate the maximum residue limits stablished in COFEPRIS (México), ANEBerries (USA), COFEPRIS (FAO), among others; to decrease toxicological effects, and by following the good agricultural practices, constant monitoring in real time during crop production and bioremediation strategies can achieve a sustainable process without compromising future generations.

Table 3. Organophosphorus pesticides damage reported.

| Pesticide | Described Damage | References |
|---|---|---|
| Malathion | Genetic harm to blood cells; immediate toxicity impacting insects; possible ecological pollution influencing water ecosystems. | Caramello et al., 2025<br>Espinoza Navarro, 2003<br>Elias, 2022 |
| Parathion | Extremely poisonous; leads to significant blocking of acetylcholinesterase resulting in immediate neurotoxic effects; potential hazards include liver and nerve damage; even minor exposure is hazardous; oxidative stress and immune toxicity have also been observed. | Aroniadou-Anderjaska, 2023<br>Yadav, 2016<br>Edwards & Tchounwou, 2005<br>Edwards, 2013 |
| Phosmet | Neurotoxic impacts consist of damage to both the central and peripheral nervous systems; inhibition of the enzyme cholinesterase; documented instances of poisoning in farming environments. | Sharma et al., 2011<br>Grillo Pizarro et al., 2018 |
| Diazinon | Intense neurotoxic effects lead to signs like shaking, excessive drooling, narrowed pupils, and extreme weakness; long-term exposure linked to nerve damage in the periphery; notable instances of serious poisoning in workplace settings reported. | Timofeeva, et al., 2008 |

### *3.2 Detection Techniques*

It is necessary to use correct quantities of organophosphorus pesticides to prevent these negative effects. Life safety can be guaranteed by using pesticides in moderation (Ghorbani et al., 2021); thus, detection and quantification through chemical sensing is a potential alternative to reduce toxicity. Liquid, gas, and capillary electrophoresis chromatography along with both liquid and gas chromatography connected to mass spectrometry, are the primary traditional detection techniques (Azizi et al., 2021; Soltani et al., 2021; Liu et al., 2023). Consequently, the machinery is costly, requires a significant amount of time, and necessitates trained personnel to operate, which limits its application for on-site testing.

The employment of electrochemical, electrochemiluminescent, fluorescent and colorimetric organophosphorus aptasensors has become to a rapid and reliable method for detection due to their sensitivity, selectivity, design, and low cost (Khosropour et al., 2022).

An example of sensor developed is the boron nitride quantum dots-graphene oxide/glassy carbon electrode

that in fire conditions, some products, such as carbon oxides, Sulphur oxides, and phosphorus oxides, are produced (*Sigma-*

(BNQDs/GO/GCE) voltametric sensor was synthesized by a hydrothermal method to simultaneously detect direct redox reactions with parathion-methyl, chlorpyrifos and diazinon in aqueous samples (Zhou et al., 2023).

Another is the two-signal fluorescent sensor was created to identify OPPs. Elevated levels of OPPs resulting in a reduction of cyan fluorescence in glutathione-synthesized gold nanoclusters (GSH-AuNCs) while enhancing the orange fluorescence. This sensor features a linear dynamic range from 10 to 2000 ng/mL and has a detection threshold of 2.05 ng/mL (Wang et al., 2024), which is important because of its applicability in several environments such as water, soil and food products.

### *3.3 Decomposition*

Main drawbacks in breaking down OPPs consist of their significant chemical resilience, which slows their degradation, and the complicated nature of the environmental contexts in which they remain. Conventional degradation techniques frequently fall short due to insufficient decomposition or the creation of harmful products. Some of the most reported decomposition processes are *Aldrich, 2016*). Degradation methods that include ultrasonic techniques, such as Fenton, photolysis, or the use of catalysts like zinc oxide, hydrogen peroxide, or titanium dioxide, have been investigated. It appears that ultrasonic methods, either alone or in combination with other techniques, can effectively assist in breaking down organic phosphorus pesticides in water (Allawi & AL-Mukhtar, 2024).

The photodegradation of dimethoate has been assessed, with optimal conditions found at a pH of 9 and a concentration of 500 mg/L, using a xenon lamp as the light source. An efficiency of 94. 31% was achieved, and the main photodegradation products identified were omethoate, O,O,S-trimethyl thiophosphorothioate, N-methyl-2-sulfanylacetamide, O,O,O-trimethyl thiophosphate, O,O,S-trimethylphosphorothiate, and O,O,O-trimethyl phosphoric ester. These are generally considered harmful to varying degrees and are less toxic than the parent compound but can still induce oxidative stress, DNA damage, and mitochondrial dysfunction in non-target organisms, including aquatic species and mammals (Lian et al., 2021). Finally, another decomposition process is Bioremediation, which is an environmentally friendly, can mineralize OPPs completely; cost-effective and sustainable.

### *3.4 Bioremediation*

The microorganisms found in the soil, including fungi, actinomycetes, bacteria, and nitrogen-fixing bacteria, may be influenced by these insecticides during the initial 14 days. Nonetheless, after a period of 28 days, signs of adaptation become evident, along with a rise in the number of colonies. At lower levels (10 mg/L), white rot fungi such as *Pleurotus sajor-caju* and *Phanerochaete chrysosporium* can eliminate as much as 87. 7% and 81. 8% of dimethoate, respectively, and 69. 20% and 68. 30% of parathion. Furthermore, the presence of insecticides sparked the production of ligninolytic enzymes such as lignin peroxidase, laccase, and manganese peroxidase (Al-Rajhi et al., 2024).

## 4. Conclusion

Organophosphorus pesticides play a crucial role in maintaining productivity and quality in food production; however, it is essential advancing integrated, sustainable, and effective detection and quantification methods is essential for reducing the harmful impacts of organophosphates and encouraging a more responsible and safer agricultural and environmental development with effective elimination and bioremediation strategies. These measures are fundamental to safeguard human health, preserving environmental quality, and fostering sustainable development.

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## References

Ajiboye, T. O., Oladoye, P. O., Olanrewaju, C. A., & Akinsola, G. O. (2022). Organophosphorus pesticides: Impacts, detection and removal strategies. *Environmental Nanotechnology, Monitoring & Management*, 17, 100655. DOI: https://doi.org/10.1016/j.enmm.2022.100655

Allawi, M. H., & AL-Mukhtar, R. S. (2024). Review and comparison for organophosphorus pesticide elimination processes. In AIP Conference Proceedings (Vol. 3009, No. 1). AIP Publishing. DOI: https://doi.org/10.1063/5.0190820

Al-Rajhi, A. M., Saddiq, A. A., Ismail, K. S., Abdelghany, T. M., Mohammad, A. M., & Selim, S. (2024). White rot fungi to decompose organophosphorus insecticides and their relation to soil microbial load and ligninolytic enzymes. *BioResources*, *19*(4), 946. DOI: https://doi.org/10.15376/biores.19.4.9468-9476

Aroniadou-Anderjaska, V., Figueiredo, T. H., de Araujo Furtado, M., Pidoplichko, V. I., & Braga, M. F. (2023). Mechanisms of organophosphate toxicity and the role of acetylcholinesterase inhibition. *Toxics*, *11*(10), 866. DOI: https://doi.org/10.3390/toxics11100866

Azizi, A., Shahhoseini, F., Langille, E. A., Akhoondi, R., & Bottaro, C. S. (2021). Micro-gel thin film molecularly imprinted polymer coating for extraction of organophosphorus pesticides from water and beverage samples. *Analytica Chimica Acta*, *1187*, 339135. DOI: https://doi.org/10.1016/j.aca.2021.339135

Bokade, P., Gaur, V. K., Tripathi, V., Bobate, S., Manickam, N., & Bajaj, A. (2023). Bacterial remediation of pesticide polluted soils: Exploring the feasibility of site restoration. *Journal of Hazardous Materials*, 441, 129906. DOI: https://doi.org/10.1016/j.jhazmat.2022.129906

Bose, S., Kumar, P. S., & Vo, D. V. N. (2021). A review on the microbial degradation of chlorpyrifos and its metabolite TCP. *Chemosphere*, *283*, 131447. DOI: https://doi.org/10.1016/j.chemosphere.2021.131447

Caño, J. G., Bareche, J. O., Justribó, M. T., & Rabés, J. D. (2007). Intoxicación por organofosforados. SEMERGEN-Medicina de Familia, 33(1), 21-23. DOI: 10.1016/S1138-3593(07)73839-X

Caramello, C. S., Cowper-Coles, F., Domitrovic, H. A., Jorge, M. J., & Jorge, L. C. (2025). Análisis de los efectos genotóxicos del malatión en Rhamdia quelen mediante el test de micronúcleos. *Brazilian Journal of Animal and Environmental Research*, *8*(1), e78270-e78270. DOI: https://doi.org/10.34188/bjaerv8n1-135

Chen, Q., Sun, Y., Liu, S., Zhang, J., Zhang, C., Jiang, H., ... & Zhang, K. (2021). Colorimetric and fluorescent sensors for detection of nerve agents and organophosphorus pesticides. *Sensors and Actuators B: Chemical*, *344*, 130278. DOI: https://doi.org/10.1016/j.snb.2021.130278 https://doi.org/10.1016/j.snb.2021.130278

Codex Alimentarius, International Food Standards. (2004). Pesticides Database Search, 49-Malathion. Retrieved May 23, 2025 from https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/pesticide-detail/es/?p_id=49

Codex Alimentarius, International Food Standards. (2005). Pesticides Database Search, 59-Parathion-Methyl. Retrieved May 23, 2025 from https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/pesticide-detail/ru/?p_id=59

Codex Alimentarius, International Food Standards. (2015). Pesticides Database Search, 103-Phosmet. Retrieved May 23, 2025 from https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/pesticide-detail/fr/?p_id=103

Codex Alimentarius, International Food Standards. (2023). Request for comments at Step 3 on the recommendations of the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) (2022), Acceptable daily intakes, acute reference doses, recommended maximum residue levels, supervised trials median residue values and other values recorded by the 2022 JMPR meeting, Diazinon. Retrieved May 23, 2025 from https://www.fao.org/fao-who-codexalimentarius/sh-proxy/es/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FCircular%252520Letters%252FCL%2525202023-22%252Fcl23_22s.pdf

Codex Alimentarius, International Food Standards. (2025). Maximum Residue Limits (MRL). Retrieved May 23, 2025 from https://www.fao.org/fao-who-codexalimentarius/codex-texts/maximum-residue-limits/en/

COFEPRIS, Consultation of Sanitary Registrations of Pesticides, Plant Nutrients and MRLs, Retrieved May 23, 2025 from https://siipris03.cofepris.gob.mx/Resoluciones/Consultas/ConWebRegPlaguicida.asp

Edwards, F. L., & Tchounwou, P. B. (2005). Environmental toxicology and health effects associated with methyl parathion exposure–a scientific review. *International Journal of Environmental Research and Public Health*, *2*(3), 430-441. DOI: https://doi.org/10.3390/ijerph2005030007

Elias, M. A., Siegloch, A. E., & Agostinetto, L. (2022). Intoxicação aguda por agrotóxicos organofosforados: uma revisão integrativa. *Research, Society and Development*, *11*(9), e11611931606-e11611931606. DOI: DOI: https://doi.org/10.33448/rsd-v11i9.31606

Espinoza Navarro, O. R. (2003). Efecto del insecticida organofosforado malatión sobre el aparato reproductor de la lombriz de tierra eisenia foetida como especie biocentinela.

Freyre, E. O., Valencia, A. T., Guzmán, D. D., Maldonado, I. C., Ledezma, L. E. B., Carrillo, M. F., & Escorza, M. A. Q. (2021). Oxidative stress as a molecular mechanism of exposure to organophosphorus pesticides: a review. *Current Protein and Peptide Science*, *22*(12), 890-897. DOI: https://doi.org/10.2174/1389203722666211122092309

Fu, H., Tan, P., Wang, R., Li, S., Liu, H., Yang, Y., & Wu, Z. (2022). Advances in organophosphorus pesticides pollution: Current status and challenges in ecotoxicological, sustainable agriculture, and degradation strategies. *Journal of Hazardous Materials*, *424*, 127494. DOI: https://doi.org/10.1016/j.jhazmat.2021.127494

Ganie, S. Y., Javaid, D., Hajam, Y. A., & Reshi, M. S. (2022). Mechanisms and treatment strategies of organophosphate pesticide induced neurotoxicity in humans: A critical appraisal. *Toxicology*, *472*, 153181. DOI: https://doi.org/10.1016/j.tox.2022.153181

Gbadamosi, M. R., Abdallah, M. A. E., & Harrad, S. (2021). A critical review of human exposure to organophosphate esters with a focus on dietary intake. Science of the Total Environment, 771, 144752. DOI: https://doi.org/10.1016/j.scitotenv.2020.144752

Gbadamosi, Muideen Remilekun, Mohamed Abou-Elwafa Abdallah, and Stuart Harrad. "A critical review of human exposure to organophosphate esters with a focus on dietary intake." *Science of the Total Environment* 771 (2021): 144752. DOI: https://doi.org/10.1016/j.scitotenv.2020.144752

Ghorbani, M., Mohammadi, P., Keshavarzi, M., Saghi, M. H., Mohammadi, M., Shams, A., & Aghamohammadhasan, M. (2021). Simultaneous determination of organophosphorus pesticides residues in vegetable, fruit juice, and milk samples with magnetic dispersive micro solid-phase extraction and chromatographic method; recruitment of simplex lattice mixture design for optimization of novel sorbent composites. *Analytica Chimica Acta*, *1178*, 338802. DOI: https://doi.org/10.1016/j.aca.2021.338802

Grillo Pizarro, Á., Achú Peralta, E., Muñoz-Quezada, M. T., & Lucero Mondaca, B. (2018). Exposición a plaguicidas organofosforados y polineuropatía periférica en trabajadores de la región del Maule, Chile [Exposure to organophosphate pesticides and peripheral polyneuropathy in workers from Maule Region, Chile]. *Revista espanola de salud publica*, *92*, e201803006.

Khosropour, H., Kalambate, P. K., Kalambate, R. P., Permpoka, K., Zhou, X., Chen, G. Y., & Laiwattanapaisal, W. (2022). A comprehensive review on electrochemical and optical aptasensors for organophosphorus pesticides. *Microchimica Acta*, *189*(9), 362. https://doi.org/10.1007/s00604-022-05399-y

Lian, L., Jiang, B., Xing, Y., & Zhang, N. (2021). Identification of photodegradation product of organophosphorus pesticides and elucidation of transformation mechanism under simulated sunlight irradiation. *Ecotoxicology and Environmental Safety*, *224*, 112655. DOI: https://doi.org/10.1016/j.ecoenv.2021.112655

List of Authorised Products. Strawberry. In compliance with the United States (2021). National Association of Berry Exporters (ANEBERRIES A. C.).

Liu, R., Yi, G., Ji, B., Liu, X., Gui, Y., Xia, Z., & Fu, Q. (2022). Metal–Organic Frameworks-Based Immobilized Enzyme Microreactors Integrated with Capillary Electrochromatography for High-Efficiency Enzyme Assay. *Analytical Chemistry*, *94*(17), 6540-6547. DOI: https://doi.org/10.1021/acs.analchem.1c05586

Meng, L. W., Chen, M. L., Yuan, G. R., Zheng, L. S., Dou, W., Peng, Y., ... & Wang, J. J. (2023). An antenna-abundant glutathione S-transferase BdGSTd8 participates in detoxification of two organophosphorus insecticides in Bactrocera dorsalis (Hendel). *Journal of Agricultural and Food Chemistry*, 71(22), 8400-8412. DOI: https://doi.org/10.1021/acs.jafc.3c01563

National Center for Biotechnology Information (2025). PubChem Compound Summary for CID 4004, Malathion. Retrieved May 23, 2025 from https://pubchem.ncbi.nlm.nih.gov/compound/Malathion.

National Center for Biotechnology Information (2025). PubChem Compound Summary for CID 4004, Malathion. Retrieved October 22, 2025 from https://pubchem.ncbi.nlm.nih.gov/compound/Malathion.

Ponce, G., Cantú, P. C., Flores, A., Badii, M., Zapata, R., López, B., & Fernández, I. (2006). Modo de acción de los insecticidas. *Revista salud pública y nutrición*, 7(4).

Prathiksha, J., Narasimhamurthy, R. K., Dsouza, H. S., & Mumbrekar, K. D. (2023). Organophosphate pesticide-induced toxicity through DNA damage and DNA repair mechanisms. *Molecular Biology Reports*, *50*(6), 5465-5479. DOI: https://doi.org/10.1007/s11033-023-08424-2

Sarlak, Z., Khosravi-Darani, K., Rouhi, M., Garavand, F., Mohammadi, R., & Sobhiyeh, M. R. (2021). Bioremediation of organophosphorus pesticides in contaminated foodstuffs using probiotics. *Food Control*, *126*, 108006. DOI: https://doi.org/10.1016/j.foodcont.2021.108006

Sharma, A. K., Gaur, K., Tiwari, R. K., & Gaur, M. S. (2011). Computational interaction analysis of organophosphorus pesticides with different metabolic proteins in humans. *Journal of biomedical research*, *25*(5), 335–347. https://doi.org/10.1016/S1674-8301(11)60045-6

Sigma-Aldrich; Safety Data Sheet for Malathion. Product Number: 36143, Version 5.4 (Revision Date 22/05/2025). Available from, as of June 1, 2016: https://www.sigmaaldrich.com/safety-center.html

Singh, A., Singh, A., Singh, A., Singh, P., Singh, V., Singh, Y., ... & Chauhan, A. (2023). Chemistry, Metabolism and Neurotoxicity of Organophosphorus Insecticides: A Review. *Nature Environment & Pollution Technology*, *22*(4).

Singh, B. K., & Walker, A. (2006). Microbial degradation of organophosphorus compounds. *FEMS microbiology reviews*, *30*(3), 428-471. DOI: https://doi.org/10.1111/j.1574-6976.2006.00018.x

Soltani, S., Sereshti, H., & Nouri, N. (2021). Deep eutectic solvent-based clean-up/vortex-assisted emulsification liquid-liquid microextraction: Application for multi-residue analysis of 16 pesticides in olive oils. Talanta, 225, 121983. DOI: https://doi.org/10.1016/j.talanta.2020.121983

Tanveer, S., Ilyas, N., Akhtar, N., Akhtar, N., Bostan, N., Hasnain, Z., ... & Fitriatin, B. N. (2024). Unlocking the interaction of organophosphorus pesticide residues with ecosystem: Toxicity and bioremediation. *Environmental research*, *249*, 118291. DOI: https://doi.org/10.1016/j.envres.2024.118291

Timofeeva, O. A., Sanders, D., Seemann, K., Yang, L., Hermanson, D., Regenbogen, S., Agoos, S., Kallepalli, A., Rastogi, A., Braddy, D., Wells, C., Perraut, C., Seidler, F. J., Slotkin, T. A., & Levin, E. D. (2008). Persistent behavioral alterations in rats neonatally exposed to low doses of the organophosphate pesticide, parathion. *Brain research bulletin*, *77*(6), 404–411. https://doi.org/10.1016/j.brainresbull.2008.08.019

Venkatesan, T., Chethan, B. R., & Mani, M. (2022). Insecticide resistance and its management in the insect pests of horticultural crops. *Trends in horticultural entomology*, 455-490. DOI: https://doi.org/10.1007/978-981-19-0343-4_14

Wang, X., Yu, H., Li, Q., Tian, Y., Gao, X., Zhang, W., ... & Li, F. (2024). Development of a fluorescent sensor based on TPE-Fc and GSH-AuNCs for the detection of organophosphorus pesticide residues in vegetables. *Food Chemistry*, 431, 137067. DOI: https://doi.org/10.1016/j.foodchem.2023.137067

Yadav, A. (2021). In vitro studies on the modulatory effects of nutraceuticals and gene polymorphisms on organophosphate pesticide-induced genotoxicity as analyzed by the comet assay. *International Journal on Nutraceuticals, Functional Foods and Novel Foods*. DOI: http://doi.org/10.17470/NF-016-1028-2

Zhou, C., Feng, J., Tian, Y., Wu, Y., He, Q., Li, G., & Liu, J. (2023). Non-enzymatic electrochemical sensors based on nanomaterials for detection of organophosphorus pesticide residues. *Environmental Science: Advances*, 2(7), 933-956. DOI: https://doi.org/10.1039/D3VA00045A