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# EFFECT OF DELTAMETHRIN INSECTICIDE SPRAYED FREQUENCIES TOWARDS *Capsicum frutescens*

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**Abstract**
Deltamethrin is a synthetic pyrethroid insecticide with an extremely high activity level against many insects. It acts by both direct contact and ingestion. However, the application of this insecticide needs to be tested to understand the effect of its sprayed frequency on plant growth. The study aimed to investigate the effect of deltamethrin insecticide exposure on *Capsicum frutescens.* This experiment used an insecticide with a 2.8% active ingredient of deltamethrin diluted to 0.07% (v/v) according to product recommendation doses and sprayed on the *C. frutescens* plants at different frequencies for two weeks. The measured parameters are deltamethrin insecticide's effect on plant leaves (visual inspection, starch, and chlorophyll analysis) and soil (pH, water content and organic content). Results show that the deltamethrin insecticides successfully inhibited the invasion of aphids; however, the plant leaves gave positive signs of phytotoxicity. Other than that, the spray frequencies reduced the plants' starch, and chlorophyll content caused the green color to become less intense. The plant soil analysis found that the deltamethrin insecticide at both sprayed frequencies had caused an increase in the soil pH and reduced water and organic content. Overall, the application of deltamethrin at these studied frequencies has been found to detrimentally impact both the plants' growth and the soil's quality. Therefore, it is imperative to optimize the exposure of this insecticide by allowing minimal frequencies lower than those tested in this study.

**Keywords**: Deltamethrin, spray frequency, *Capsicum frutescens*, soil analysis, leaf analysis

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## Introduction

In agriculture, various disease-causing organisms, including insects, larvae, pathogenic fungi, viruses, and weeds, severely affect the growth and productivity of crops. Insecticides are commonly used to manage insect pests, which can damage crops, transmit diseases, or be a nuisance to humans and animals (Pathak et al., 2022). Insecticides play a vital role in agriculture and public health by helping to manage insect populations that can pose economic and health risks (Tudi et al., 2021).

According to Worthing and Walker (1987), synthetic pyrethroid insecticide deltamethrin has a very high level of action against a variety of insects, including Lepidoptera, Hemiptera, Diptera, and Coleoptera (IARC, 1991). It acts through direct contact and ingestion (Worthing & Walker, 1987). Cutaneous contact and digestion of the synthetic pyrethroid disrupts the neurological system of insects, which causes their death (Bradberry et al., 2005). Deltamethrin has been the most popular and frequently used insecticide in the world since 1974, and it has gained popularity among pest control operators and other individuals. Because of its durability, residual activity, and low toxicity to mammals, it is commonly employed in agriculture (Laskowski, 2002; Ismail et al., 2015).

Deltamethrin's numerous applications varied from crop protection to residential insect control. Because insecticide and their residue have such an enormous environmental impact, a detailed understanding of their physical, biological, and chemical consequences is critical (Xuang et al., 2000). According to Ardley (1999), approximately 0.1% of the insecticide used reaches the target pest, with the remainder affecting the environment. Deltamethrin is not mobile in the environment due to its high particle adsorption, water solubility, and low application rate. However, it still threatens the ecosystems in which it is used (Bhanu et al., 2011; Ismail et al., 2015). Pyrethroids generate oxidative stress, which modifies DNA, RNA, protein, lipid, and carbohydrate molecules (Xu et al., 2015). However, public awareness of the possible adverse effects of insecticide use is still low. Further research should be carried out to clarify the detrimental action of pyrethroid. Proper dissemination of the results seems essential for public health (Hołyńska-Iwan & Szewczyk-Golec, 2020).

Insecticides have been observed to infiltrate the food chain via the biomagnification process, impacting both consumers and farmers. The insecticide may leave residues on fruits, vegetable crops, and even other processed food items, indicating that insecticides are non-recalcitrant chemicals that retain their toxicity even after detoxification and degradation processes (González-Rodríguez et al., 2011). Insecticide sprays also could affect non-target vegetation directly or drift or volatilize from the treated region, contaminating air, soil, and non-target agents (Aktar et al., 2009). In addition, due to extensive agricultural practices, the insecticide that was applied ends up leaching into the soil. The physical and chemical properties of soil and pesticides and environmental conditions influence their bioaccumulation (Pathak et al., 2022). It is challenging to transform into less toxic forms through chemical and biological processes, negatively affecting plant health and human consumption (Alengebawy et al., 2021). In addition, due to the lack of data on the sprayed frequency of deltamethrin, especially on *Capsicum frutescen*s, this study aims to evaluate the effect of sprayed frequency on the quality of plant soil and leaves.

## Methods

**The sample treatment with deltamethrin insecticide.**

The *Capsicum frutescens* seeds were bought from a nursery, sown in 12 poly bags, and grown at Rancangan Kampung Tersusun Batu 3, Tapah, Perak, Malaysia. The plant was watered at 150 ml for each polybag daily and supplemented with commercial fertilizers. To study the effect of insecticides on plant growth and soil performance, commercial insecticides containing 2.8% deltamethrin were diluted to a concentration of 0.07% (v/v) according to standard doses. The insecticide was applied as a direct spray treatment at two different frequencies. Frequent 1: once every three days, and Frequent 2: sprayed daily. The volume of deltamethrin insecticide sprayed for each frequency is 100 ml using a hand sprayer. Control plants were utilized, ensuring they had no exposure to the insecticide. This step was repeated for two weeks.

**Parameters measured**

Six different parameters were measured: the effect of the insecticide on the *Capsicum frutescens* plant by visual inspection, plant leaf chlorophyll content, presence of starch in the leaf, soil pH, soil water content, and soil organic content.

**i. Visual inspection**

The plant's overall appearance was observed, including its size, shape, color, and general health. Any abnormalities such as wilting, discoloration, stunted growth, or signs of disease or pest damage were recorded.

**ii. Starch analysis**

Water in a beaker (250 ml) was boiled, and the leaf was placed in the boiling water for one minute until it floated. The leaf was removed and placed in a boiling tube with 40 mL of 95% ethanol. The boiling tube was placed in a beaker of hot water (no heating) for 10 minutes. The boiling tube was removed from the beaker, and the leaf was removed carefully. The leaf was rinsed in hot water using forceps and spread out on a tile. Drops of iodine were placed over the leaf, and the black areas of the leaf that turned blue-black showed the occurrence of photosynthesis. The experiment was repeated with leaves from different plants.

**iii. Chlorophyll analysis**

Leaf (250 mg) from the plant of each treatment group were macerated with 10 mL of 80% acetone using a pestle and mortar. The extracts were centrifuged at 3000 rpm for 10 minutes. The supernatants were transferred into a 25 mL volumetric flask and made up to 25 mL using 80% acetone. The colour intensity was at 645 nm, 663 nm for chlorophyll, and 625 nm for chlorophyll b, respectively, using a spectrophotometer to read the green pigment. The cuvette was cleaned each time before inserting another solution to get an accurate reading.

**iv. Soil pH**

The wet soil samples (20 ml) were placed into beakers, and 30 ml of distilled water was added. The mixture was then stirred using a glass rod until it became homogeneous. The soil pH was determined using a pH meter and recorded.

**v. Soil water content**

The soil samples were oven-dried at 110°C until they reached a constant weight. The soil water content was calculated using Equation 1 below.

$$\text{Water content (\%)} = \left(\frac{\text{Initial weight} - \text{Dry weight}}{\text{Initial weight}}\right) \times 100 \qquad \text{(Equation 1)}$$

**vi. Soil organic matter content**

The soil organic matter content was measured using the loss ignition method. Soil sample (10 grams) was placed into the crucible and dried in an oven at a relatively low temperature (105°C) until a constant weight was achieved. This is to remove any remaining water content. The crucible and soil were then weighed after drying, and the weight was recorded. For ignition, the crucible with the dried soil was placed into the furnace preheated to 300°C for 1 hour. After ignition, the crucible is removed from the oven and let to cool in a desiccator. The weight loss due to ignition was calculated using Equation 2 below.

$$\text{Organic content (\%)} = \left(\frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}}\right) \times 100 \qquad \text{(Equation 2)}$$

## Result and Discussion

**Visual inspection on sprayed *Capsicum frutescens* plant**

Several symptoms of insecticide toxicity in morphology are known with the presence of signs such as yellowing (chlorosis), stunting, necrosis (death), vein clearing, and deformations on plant leaves (Kim et al., 2021). This research recorded the visual inspection for three treatments: Control, Frequency 1 (F1) & Frequency 2 (F2). The main part of the plant that was inspected and observed was the leaf of *C. frutescens,* tabulated in Figure 1.

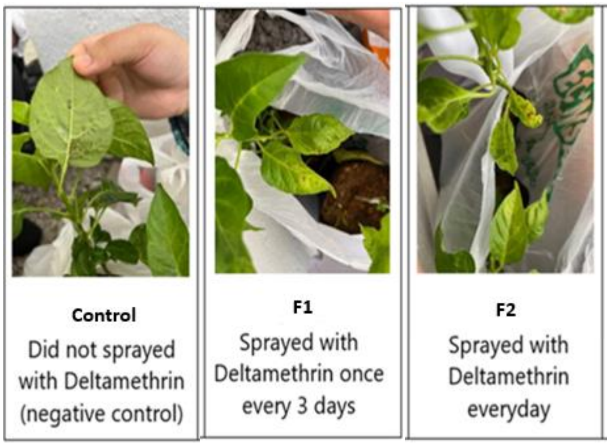


Figure 1. *C. frutescens* leaf after one month treated with deltamethrin.

Based on Figure 1, the control plant contains aphids under the leaf's surface. Aphid sp. is a type of insect from the Aphididae family that has been around for hundreds of years where it is known as an animal that damages plants, especially food plants such as *C. frutescens* leaf (Gallo-Franco et al., 2019). Adult aphids can usually be seen on the chili plant's flower part and the leaves' underside. Aphids usually suck plant sap on soft cells using devices on the head to suck sap from the 'phloem cells' of the plant called 'stylets' into its stomach (Branco et al., 2023). The transmission of the Tobacco mosaic virus carried by these aphids in *C. frutescens* will occur during the process of inhaling this water, where the stylet will continue to pierce and enter new cells that are not yet contaminated. Chili curl disease caused by the Cucumber mosaic virus is often spread by aphids found on chili plants (Wamonje et al., 2020).

This study found that the application of deltamethrin insecticides had successfully inhibited the invasion of aphids on the *C. frutescens* plant. This explains that no population of aphids is observed on the plant sample. Insecticide deltamethrin is a pyrethroid that is used to control pests towards *C. frutescens,* which is the subject of this study. Based on a recent article, deltamethrin is used to kill the neunote larvae of the green lacewing, caged bees, and the larvae exposed to the aqueous extract of hot pepper fruits (Tomé et al., 2014). Deltamethrin has rapid action on target larvae because it contains pyrethroids as an active ingredient whose mode of action is the dysfunction of sodium channels, and it acts on both the central and peripheral nervous systems, thus resulting in rapid paralysis of targets (Silver et al., 2014). Deltamethrin, mainly, is toxic or highly toxic to pollinating insects and beneficial predators. It could be the source of pest outbreaks, particularly aphids (Skouras et al., 2021).

However, results show that the sprayed leaves with the insecticides at frequencies of F1 and F2 possess signs of phytotoxicity with yellow leaves, and the leaves are most likely curling compared to the control. When administered in elevated concentrations or adverse environmental conditions, insecticides induce phytotoxicity in plants (Guedes et al., 2023). Phytotoxic effects on plants can manifest as leaf necrosis, growth inhibition, deformations, and changes in plant tissue structure. These effects can harm plant development and crop quality (Barbaś et al., 2023). Overall, this study found that the application of deltamethrin insecticides had successfully controlled or reduced the invasion of aphids on plants; however, the frequency with which they were applied harms the leaves' growth.

**Leaf starch**

Iodine was employed to conduct leaf starch testing, resulting in a noticeable color transformation of the leaf from green to blue-black. This compelling phenomenon serves as empirical evidence indicating the presence of starch, affirming the occurrence of photosynthesis, as outlined by Cochran et al. (2008). Based on Figure 2, it is evident that the leaf in the control treatment exhibits the most pronounced blue-black coloration compared to the F1 leaf, which demonstrates a reduced blue-black hue. Conversely, the F2 leaf displays the least blue-black coloration, indicating the absence of starch within the leaf.

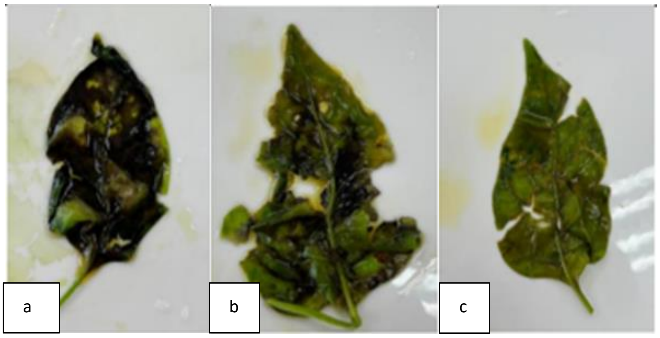


Figure 2. The presence of starch on plant leaf a) control b) F1 c) F2.

Insecticides can potentially interfere with photosynthesis, the process by which plants and other organisms convert light energy into chemical energy (in the form of glucose) using carbon dioxide and water (Smith & Brown, 2005). Some insecticides also can accumulate in leaves and directly interfere with the biochemical processes involved in photosynthesis (Alengebawy et al., 2021). This interference occurs due to several mechanisms, including damage to chloroplasts, disruption of enzymes, alteration in plant cell membrane permeability, and disruption of plant nutrient balance (Muhammad et al., 2021).

Sharma et al. (2012) also stated that excessive insecticide exposure could cause plant stress responses that lead to changes in physiological processes, including photosynthesis. This stress response, specifically oxidative stress, causes the chlorophyll's proteins and pigments to degrade, ultimately lowering the effectiveness of plants' photosynthetic processes (Muñoz, P., & Munné-Bosch, 2018).

**Chlorophyll content**

Monitoring chlorophyll content enables early detection of such stressors, allowing timely interventions to mitigate damage and maintain plant health. According to Table 1, the leaf extract from the control treatment has the highest chlorophyll content than plant samples sprayed with insecticides at both F1 and F2 frequencies.

Table 1. Chlorophyll content of leaf extract from plants sprayed with insecticides at different frequencies.

| Spray frequency | Chlorophyll a (mg/g) | Chlorophyll b (mg/g) |
|---|---|---|
| control | 1.88 ± 0.29 | 1.30 ± 0.32 |
| F1 | 1.37 ± 0.52 | 0.58 ± 0.55 |
| F2 | 1.14 ± 0.44 | 1.19 ± 0.67 |

Consequently, the lower chlorophyll values observed in samples exposed to insecticides in this study align with the low presence of starch on the plant leaves. Recent research by Zheryakov and Zheryakova (2021) emphasizes the direct Impact of insecticides on chloroplasts. Insecticides have been identified to inhibit key enzymes crucial for chlorophyll biosynthesis. This inhibition disrupts chloroplast function, compromising the plant's ability to synthesize and maintain optimal chlorophyll levels. In addition, insecticides can disrupt nutrient uptake by plant roots, exacerbating nutrient deficiencies critical for chlorophyll's molecular structure (Ishkandar et al., 2021).

**Soil pH**

Soil pH plays a pivotal role in controlling plant nutrient availability by regulating the chemical forms of various nutrients and influencing their interactions. Therefore, research on soil pH holds significant importance in agriculture, as emphasized by Oshunsanya (2019) and Wang et al. (2022). The findings regarding the effects of insecticides on soil pH, depicted in Figure 3, shed light on this critical aspect.

Notably, the control plants exhibited an average pH of 7.6, while pH levels were 7.8 for F1 and 7.9 for F2. These results reveal a progressive increase in soil pH with elevated spray frequencies, underscoring the substantial Impact of insecticide applications on soil acidity levels.

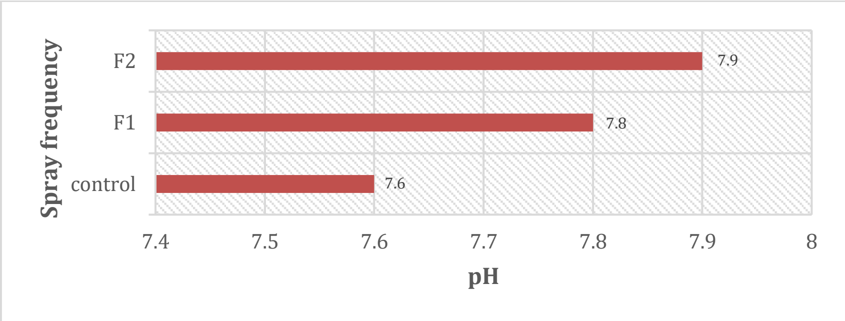


Figure 3. Average effects of insecticide on the pH of soil.

The insecticides applied at both frequencies interact with soil components in ways that alter the balance of acidic and alkaline compounds, showing an increment in the soil pH value. This shift towards alkalinity could potentially degrade soil quality, as alkaline soil conditions may reduce the total ion concentration and activity within the soil solution (Laurent et al., 2020). This phenomenon can be attributed to the Impact of insecticides on soil microbial communities. These chemicals may suppress the growth or activity of acid-producing bacteria or fungi, crucial for maintaining soil pH balance. Consequently, decreasing acid-producing microbial populations can gradually elevate soil pH levels over time (Killham, 1994; Singh and Walker, 2006).

**Water Content**

Each soil sample was treated under three different treatments: Control, Frequency 1 (F1), and Frequency 2 (F2), and the results of water content are shown in Figure 4.

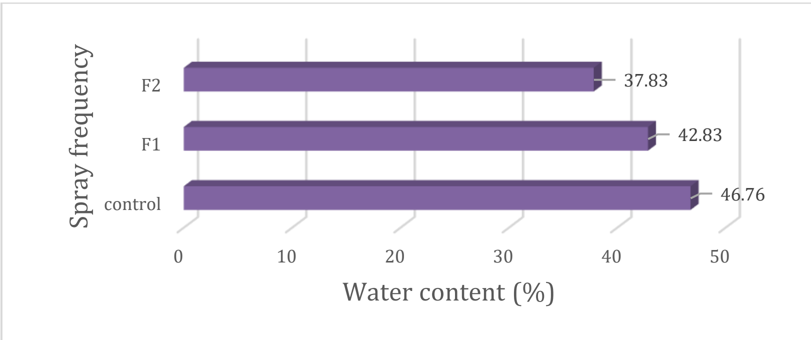


Figure 4. The water content (%) in three different treatments of soil.

Based on the findings in Figure 4, the control group exhibited the highest water content at 46.76%, followed by F1 at 42.83%, and the lowest water content was observed in F2 at 37.83%. These results suggest that applying insecticide at different frequencies has a discernible impact on soil water content. This observation highlights the complex interconnection between insecticide applications and soil microorganisms, especially those pivotal for decomposition and nutrient cycling. The study also corroborates that decreased water content and elevated soil pH are influenced by reduced microbial activity in the soil of insecticide-sprayed plants. This disruption in microbial function may impede natural water retention and absorption processes, consequently resulting in diminished water content levels (Smith et al., 2020). When insecticides disrupt these microbial populations, the breakdown of organic residues is hindered, leading to a slower rate of organic matter decomposition. Decreased decomposition can lead to increased runoff and reduced water infiltration (Pathak et al., 2022). Thus, this led to explaining the low water content in F3.

**Organic content**

Based on the findings in Figure 5, the organic content percentage in the control group is notably the highest at 93.93%, succeeded by the organic content percentages in F1 (81.07%) and F2 (77.37%), respectively.

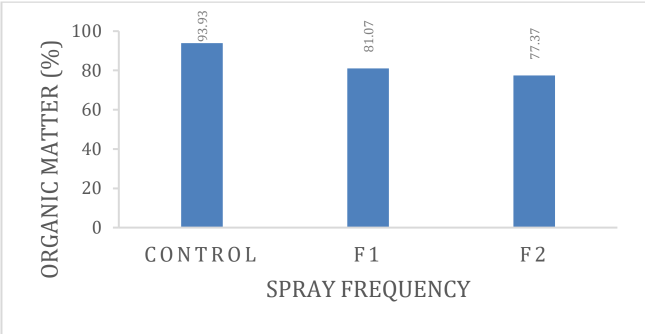


Figure 5. Percentage of organic matter in soil after plant sprayed with deltamethrin at different frequencies.

This disparity suggests that the introduction of the insecticide deltamethrin at both frequencies induces soil contamination, consequently diminishing the organic content percentage. Insecticide contamination risks soil quality by altering its chemical and biological attributes, which can adversely affect crop productivity (Tudi et al., 2021). Such contamination has been associated with reductions in soil microbial biodiversity and enzymatic activity, pivotal indicators of soil resilience against pollutants, as well as the degradation of soil organic matter (Carpio et al., 2021). A previous study on the application of deltamethrin in cabbage-planted soil showed that deltamethrin can disrupt the microbial population in the soil, and natural biodegradation can play a significant role in the decontamination of insecticide-contaminated soil (Braganca et al., 2019). In addition, insecticide can impact soil organic matter decomposition rates and the formation of humic substances, which play a role in buffering soil pH. Insecticide residues may alter microbial activity involved in organic matter decomposition, leading to changes in the release of organic acids that contribute to soil acidity. Consequently, the reduced accumulation of organic acids can gradually increase soil pH (Jones et al., 2019).

## Conclusion

The frequencies of deltamethrin insecticides had successfully reduced the aphid invasion on plants; however, gave signs of phytotoxicity to the plant. The sprayed frequencies implemented cause an increase in soil pH and a reduction of soil organic and water content. Other than that, it reduced the chlorophyll and starch of the plant leaf and caused the green color to disappear. In summary, it can be deduced that the applied frequencies adversely impact the overall performance of the 1-month-old *C. frustescens* plants. Therefore, minimizing exposure by reducing the spray frequencies even further than those applied in this study is advisable. In addition, using Integrated Pest Management methods, including natural controls, will help strike a balance between effective pest control and eco-friendly practices. This approach ensures the well-being of chili plants while supporting sustainable agriculture.

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**Author Contribution**

SNH: Conceived and designed the experiments, analyzed the data, and wrote the manuscript; SMM and NNR: Processed the data and contributed to manuscript writing; SNAA and WNHWA: Provided expertise in data analysis and interpretation and critically reviewed the manuscript for intellectual content; AMN: Contributed in data collection, and manuscript preparation; MFMK: Provided administrative support.

**Conflict of Interest**

Authors declare no conflict of interest.

**References**

Aktar, M. W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary Toxicology*, *2*(1), 1-12.

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy metals and pesticide toxicity in agricultural soil and plants: Ecological risks and human health implications. *Toxics*, *9*(3), 42-75.

Ardley, J.H. (1999). Pesticide considerations on environmental concern. *Agricultural Sciences 12*(2), 21-24.

Barbaś, P., Pietraszko, M., Pszczółkowski, P., Skiba, D., & Sawicka, B. (2023). Assessing Phytotoxic Effects of Herbicides and Their Impact on Potato Cultivars in Agricultural and Environmental Contexts. *Agronomy*, 14(1), 85-112.

Bhanu, S., Archana, S., Ajay, K., Bhatt, J.L., Bajpai, S.P., Singh, P.S. & Vandana, B. (2011). Impact of deltamethrin on environment, use as an insecticide and its bacterial degradation: A preliminary study. *International Journal Environment Sciences 1*(5), 977-985.

Bragança, I., Mucha, A. P., Tomasino, M. P., Santos, F., Lemos, P. C., Delerue-Matos, C., & Domingues, V. F. (2019). Deltamethrin impact in a cabbage planted soil: Degradation and effect on microbial community structure. *Chemosphere*, *220*, 1179-1186.

Branco, M., Franco, J. C., & Mendel, Z. (2023). Sap-Sucking Forest Pests in *Forest Entomology and Pathology.* Springer, South Africa: pp. 417-456.

Bradberry, S. M., Cage, S. A., Proudfoot, A. T., & Vale, J. A. (2005). Poisoning due to pyrethroids. *Toxicological Reviews*, *24*, 93-106.

Carpio, M. J., Sánchez-Martín, M. J., Rodríguez-Cruz, M. S., & Marín-Benito, J. M. (2021). *s*, *8*(4), 32-60.

Cochran, B., Lunday, D., & Miskevich, F. (2008). Kinetic analysis of amylase using quantitative Benedict's and iodine starch reagents. *Journal of Chemical Education*, *85*(3), 401-404.

Gallo-Franco, J. J., Duque-Gamboa, D. N., & Toro-Perea, N. (2019). Bacterial communities of Aphis gossypii and Myzus persicae (Hemiptera: Aphididae) from pepper crops (*Capsicum sp*.). *Scientific Reports*, *9*(1), 5766-5778.

González-Rodríguez, R. M., Rial-Otero, R., Cancho-Grande, B., Gonzalez-Barreiro, C., & Simal-Gándara, J. (2011). A review on the fate of pesticides during the processes within the food-production chain. *Critical Reviews in Food Science and Nutrition*, *51*(2), 99-114.

Guedes, R. N. C., Biondi, A., Agathokleous, E., & Nunes-Nesi, A. (2023). (Systemic) Insecticides in Plants: Phytotoxicity, Bioactivation, or Hormesis?. *Agriculture Communications*, *1*(2003), 100002-100012.

Hołyńska-Iwan, I., & Szewczyk-Golec, K. (2020). Pyrethroids: how they affect human and animal health?. *Medicina*, *56*(11), 582-587.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (1991). Permethrin. In *Occupational Exposures in Insecticide Application, and Some Pesticides*. International Agency for Research on Cancer.

Ishkandar, C.D.M., Nawi, N.M., Janius, R., Mazlan, N., & Lin T.T. (2021). Detection of deltamethrin in cabbages using visible shortwave near-infrared spectroscopy. *Food Research, 5*(3), 273 - 280.

Ismail, B. S., Mazlinda, M., & Tayeb, M. A. (2015). The persistence of deltamethrin in Malaysian agricultural soils. *Sains Malaysiana*, *44*(1), 83-89.

Jones, A., Smith, B., & Johnson, C. (2019). Impact of pesticide residues on soil organic matter decomposition rates and soil pH regulation. *Journal of Environmental Science, 15*(3), 245-259.

Kim, J. M., Ha, J., Kim, K. H., Lee, T., Heo, J., Jung, J., & Kang, S. (2021). Identification of a novel trait associated with phytotoxicity of an insecticide etofenprox in soybean. *Journal of Pesticide Science*, *46*(2), 168-172.

Killham, K. (1994). *Soil ecology*. Cambridge University Press.

Laurent, C., Bravin, M. N., Crouzet, O., Pelosi, C., Tillard, E., Lecomte, P., & Lamy, I. (2020). Increased soil pH and dissolved organic matter after a decade of organic fertilizer application mitigate copper and zinc availability despite contamination. *Science of the Total Environment, 709*(2020*)*, 135927-135938.

Laskowski, D. A. (2002). Physical and chemical properties of pyrethroids. *Reviews of Environmental Contamination and Toxicology: Continuation of Residue Reviews*, 49-170.

Muhammad, I., Shalmani, A., Ali, M., Yang, Q. H., Ahmad, H., & Li, F. B. (2021). Mechanisms regulating the dynamics of photosynthesis under abiotic stresses. *Frontiers in Plant Science*, *11*, 615942.

Muñoz, P., & Munné-Bosch, S. (2018). Photo-oxidative stress during leaf, flower and fruit development. *Plant Physiology*, *176*(2), 1004-1014.

Oshunsanya, S. (Ed.). (2019). Introductory Chapter: Relevance of Soil pH to Agriculture. In *Soil pH for Nutrient Availability and Crop Performance.* IntechOpen, United Kingdom: pp 3-5.

Pathak, V. M., Verma, V. K., Rawat, B. S., Kaur, B., Babu, N., Sharma, A. & Cunill, J. M. (2022). Current status of pesticide effects on the environment, human health and its eco-friendly management as bioremediation: A comprehensive review. *Frontiers in Microbiology*, *13*, 962619-962648.

Sharma, P., Jha, A. B., Dubey, R. S., & Pessarakli, M. (2012). Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. *Journal of Botany*, *2012,* 1-26.

Silver, K. S., Du, Y., Nomura, Y., Oliveira, E. E., Salgado, V. L., Zhorov, B. S., & Dong, K. (2014). Voltage-gated sodium channels as insecticide targets. *Advances in Insect Physiology*, *46*, 389–433.

Singh, B.K., and Walker, A. (2006). Microbial degradation of organophosphorus compounds. *FEMS Microbiology Reviews, 30*(3), 428-471.

Skouras, P. J., Darras, A. I., Mprokaki, M., Demopoulos, V., Margaritopoulos, J. T., Delis, C., & Stathas, G. J. (2021). Toxicity, sublethal and low dose effects of imidacloprid and deltamethrin on the aphidophagous predator ceratomegilla undecimnotata (Coleoptera: Coccinellidae). *Insects, 12,* 696-712.

Smith, J. A., & Brown, R. M. (2005). Impact of insecticides on photosynthesis in plants. *Journal of Environmental Science*, *10*(2), 153-167.

Smith, J., Jones, A., & Johnson, B. (2020). The impact of insecticides on soil microorganisms and their role in water retention. *Journal of Soil Ecology, 10*(2), 123-135.

Tomé, H.V., Pascini, T.V., Dângelo, R.A., Guedes, R. N & Martins, G. F. (2014). Survival and swimming behavior of insecticide-exposed larvae and pupae of the yellow fever mosquito *Aedes aegypti*. *Parasites Vectors, 7*, 195-214.

Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D. & Phung, D. T. (2021). Agriculture development, pesticide application and its Impact on the environment. *International Journal of Environmental Research and Public Health*, *18*(3), 1112-1135.

Wamonje, F. O., Tungadi, T. D., Murphy, A. M., Pate, A. E., Woodcock, C., Caulfield, J. C., Mutuku, J. M., Cunniffe, N. J., Bruce, T. J. A., Gilligan, C. A., Pickett, J. A., & Carr, J. P. (2020). Three aphid-transmitted viruses encourage vector migration from infected common bean (*Phaseolus vulgaris*) plants through a combination of volatile and surface cues. *Frontiers in Plant Science, 11*, 613772-6137782.

Wang, F., Wang, Q., Adams, C.A., Sun, Y., & Zhang, S. (2022). Effects of microplastics on soil properties: current knowledge and future perspectives. *Journal of Hazardous Materials, 424*, 127531-217552.

Worthing, C.R. & Walker, S.B. (1987) *The Pesticide Manual - A World Compendium*, 8th ed., Thornton Heath, British Crop Protection Council, pp. 234–235.

Xu, M. Y., Wang, P., Sun, Y. J., Wang, H. P., Liang, Y. J., Zhu, L., & Wu, Y. J. (2015). Redox status in liver of rats following subchronic exposure to the combination of low dose dichlorvos and deltamethrin. *Pesticide Biochemistry and Physiology*, *124*, 60-65.

Xuang, X., Le, L.S. & Nakatsu, C. (2000). Impact of animal waste lagoon effluents on chloropyriphos degradation in soils. *Environmental Toxicology and Chemistry, 19*, 2864-2870.

Zheryakov, E. V & Zheryakova, Y. I. (2021). Changes in the content of chlorophyll in leaves when using pesticides and micro fertilizers. *Earth and Environmental Science, 843,* 012043-012051.