Impact of chemical pesticides on mung bean (*Vigna radiata L.*) Plant and soil enzyme activities

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Abstract. Agriculture is important for food production, and adverse effects on agriculture are directly linked to human health. Several types of chemical pesticides are used to control agricultural pests to increase agricultural productivity. These pesticides have a deleterious effect on several plant processes, thereby affecting plant growth. By altering soil enzyme activity, these pesticides affect not only plant development but also soil health. Three pesticides (insecticides) that are frequently used in agriculture, cypermethrin, phorate, and malathion, were used in our experiment, and their field-recommended dosages were used. We investigated the impact of these pesticides on plant growth and soil enzyme activities. Plant growth parameters such as root length, shoot length, number of leaves, root collar diameter, total branches, and total phenolic content (TPC), chlorophyll content, and reducing sugars were also assessed using the host mung bean (*Vigna radiata L.*). Soil enzymes, including invertase, acid phosphatase, alkaline phosphatase, urease, cellulase, and protease, were used to detect the impact of pesticides on soil health. The most negative impacts on plant growth parameters were observed in malathion-based treatments. Malathion and phorate were the most affecting pesticides on soil enzymes.

Keywords: cypermethrin, phorate, malathion, plant growth, polycyclic enzyme

1. Introduction

The global population is increasing by approximately 97 million people annually and is projected to reach nearly 10 billion by 2050, intensifying pressure on global food production (Saravi & Shokrzadeh, 2011). Simultaneously, rapid urbanization and industrial expansion are reducing agricultural land, further aggravating food scarcity (Ravi & Fulekar, 2018). To meet rising food demands, modern agriculture increasingly relies on agrochemicals, such as fertilizers and pesticides, to enhance crop productivity. However, agricultural pests, including insects, weeds, and plant pathogens, continue to cause severe yield losses of up to 45%, posing a major threat to global food security (Mundt, 2014). Studies indicate that only about 0.1% of applied pesticides

effectively reach target pests, while the majority persists in the environment and contaminate soil ecosystems (Carriger et al., 2006; Uniyal et al., 2025).

The continuous use of pesticides in agriculture increases production but it has significant negative effects on soil health and it decreases soil enzymatic activities (Riah et al., 2014). There is evidence that soil enzymes may offer helpful information on how pesticides are transformed in soils (Hussain et al., 2009, Riah et al., 2014). Soil enzymes catalyze and enhance several important reactions in the soil ecosystem which help increase agricultural production and positive effect on soil quality and health. Soil enzymes are important sensitive biochemical indicators of soil health (Raiesi et al., 2014). The activity of enzymes depends on their origin and function, types, and abundance of the microbes present (Schimel et al., 2017). Soil enzymes are not only important factors in the decomposition of dead material and in promoting plant growth by controlling pathogens but these enzyme activity is also correlated with soil's physical and chemical properties (Ai et al., 2012, Dai et al., 2018). Different types of chemical pesticides are used in agriculture to improve production but pesticides negatively affect soil health and soil enzymatic activities which creates imbalance in the soil ecosystem. Pesticide application significantly alters soil enzymatic activities, including dehydrogenase, fluorescein diacetate hydrolase, acid phosphatase, alkaline phosphatase, phosphatase, β-glucosidase, cellulase, urease, and arylsulfatase, thereby disrupting key biochemical processes involved in nutrient cycling and soil fertility (Riah et al., 2014).

Mung bean (*Vigna radiata* L.), an important grain legume, is mainly cultivated in Asian countries and other regions worldwide as an important food crop. It is one of the nutritious legume grains rich in easily digestible proteins (20–32%), carbohydrates (53.3–67.1%), lipids (0.71–1.85%), vitamins, minerals, and fibre. It also includes small amounts of antinutrients such as tannins, phytic acid, hemagglutinin, polyphenols, and trypsin inhibitors (Mehta et al., 2021). Consuming mung beans can help with diabetes and obesity because they produce fewer calories during digestion, owing to their high protein content (Yao et al., 2013). In this study, we investigated the effects of commonly used pesticides on mung bean growth because mung beans are affordable, reliable and easy to germinate, and provide a useful way to examine the germination process, and also observed soil enzyme activity.

2. Material and methods

2.1. Pot treatments

Three commonly used chemical pesticides cypermethrin, phorate, and malathion were applied to evaluate their impact on plant growth and soil enzyme activities (Table 1) (Dar et al., 2022; Modak et al., 2024). Experimental soil was prepared by mixing vermicompost and field soil in the 1:2 ratios, with 3 kg of soil added to each pot (soil properties shown in Table 2). Pesticides were applied at recommended field dosages (cypermethrin 25% EC: 300 mL/acre; phorate 10G: 12 kg/acre; malathion 50% EC: 250 mL/acre). The applied concentrations of active ingredients were 0.0375 mg kg^{-1} for cypermethrin, 0.60 mg kg^{-1} for phorate, and 0.0625 mg kg^{-1} for malathion. Treated soils were distributed into three replicates per treatment, while untreated soil served as the control. Mung bean (*Vigna radiata* L., MH-1142) seeds were sown (three seeds per pot) and grown for 30 days, after which plants were harvested for analysis of growth parameters and soil enzyme activities. Commercial pesticide formulations were used in this study instead of pure active substances to better simulate real-world agricultural field conditions. Farmers typically apply pesticides in commercially available formulations at commonly recommended doses rather than using isolated active ingredients. Therefore, using commercial products improves the practical relevance and applicability of the experimental results. In addition, formulation additives such as emulsifiers and stabilizers can influence the behaviour, bioavailability, and interactions of pesticides with soil and plants. Including these components provides a more realistic assessment of pesticide impacts under actual farming practices.

Table 1: Pesticides used in experiment

S. No.	Trade Name	Common Name	Chemical class	Active substance concentration	Recommended dosage	Mode of action	Main chemical characteristics
1	Cyper-25	Cypermethrin	Pyrethroid	25% EC	300ml/acre	Disrupts sodium channel function in insect nerve cells, causing paralysis and death	Broad-spectrum insecticide, low water solubility, high photostability, moderately persistent in soil, and strongly adsorbed to soil particles
2	Thimet	Phorate	Organophosphate	10% CG	12kg/acre	Inhibits acetylcholinesterase activity, leading to insect	Systemic insecticide, highly toxic, moderate water solubility, rapid degradation under warm and moist

						acetylcholine sterase and mortality	conditions and high mobility in soil
3	Cythion	Malathion	Organophosphate	50% EC	250ml/acre	Inhibits acetylcholine sterase activity, leading to insect paralysis and mortality	Broad-spectrum insecticide, low persistence in soil, moderate water solubility, rapid biodegradation, and relatively lower mammalian toxicity compared to other organophosphates

Table 2: Properties of experimental soil

S.No	Properties Name	Soil property
1	% Clay	45.6
2	% Silt	29.1
3	% Sand	26.3
4	Textural Class	clay loam
5	pH	5.87
6	EC (dSm^{-1})	0.26
7	OC (%)	0.52

2.2. Physiological and biochemical parameters of mung bean plants

2.2.1. Plant Growth parameters

The mung bean plant harvested after 30 days of sowing, and morphological parameters of each experimental plant were studied, including root length, shoot length, number of leaves, root collar diameter, and total branch. The distance between the tap root's tip and the stem base attachment point was precisely measured to determine the length of the root. From the base of the stem to the tip, the length of the shoot was measured.

2.2.2. Total Phenolic Content in plants (TPC)

The Folin-Ciocalteu assay was used to extract TPC with some modifications. When phenols react with an oxidizing agent phosphomolybdate, in Folin-Ciocalteau reagent (FCR) in alkaline conditions, a blue-coloured complex known as molybdenum blue is formed, which is

colourimetrically detected at 650 nm (Bray and Thorpe 1954). 0.5 g of mung bean plant sample from each treatment was weighed and ground with a pestle and mortar in 10 times the volume of 80% ethanol. The homogenate was centrifuged at 10,000 rpm for 20 min. The supernatant was removed, and the residue was re-extracted with 5 times the volume of 80% ethanol. The supernatant was then centrifuged, and the supernatant was pooled. The supernatant was evaporated to dryness. The residue was dissolved in 5 mL of distilled water. 1 mL was pipetted out into test tubes. The volume in each tube was made up to 3.0 mL with distilled water. 0.5 mL of FCR was added, and after 3 min, 2.0 mL of 20% Na_2CO_3 solution was added to each tube. The tubes were thoroughly mixed and placed in a boiling water bath for 1 min, then cooled, and the absorbance was measured at 650 nm against the reagent blank. A standard curve was prepared using different concentrations of catechol (Nayak et al., 2016).

2.2.3. Chlorophyll content

The spectrophotometer was used to measure the leaf's chlorophyll content. 0.2 g of the leaves from each sample was ground in 10 mL of 80% acetone. The filtrate was transferred into test tubes, and the absorbance was measured at 645, and 663 nm. Chlorophyll a, b and total chlorophyll were estimated by the below equations.

Chlorophyll a (ug/ml)= 12.7 (A663) - 2.7 (A645)

Chlorophyll b (ug/ml)= 22.9 (D645) - 4.7(D663)

Total Chlorophyll (ug/ml)= (D645 X 1000/34.5)

2.2.4 Estimation of reducing sugars in plants

Sugars with reducing properties, arising from a potential aldehyde or keto group is called reducing sugars. 100 mg of the mung bean plant samples were weighed, and the sugars were extracted with the help of hot 80% ethanol twice (5 mL each time). The supernatant was collected and evaporated by keeping it in a water bath at 80 °C. The sugars were dissolved by adding 10 mL of distilled water was added. 0.5 mL of the extract was pipetted out into test tubes, and the volume in all the tubes was equalized to 3 mL with distilled water. 3 mL of DNS reagent (3,5-Dinitrosalicylic acid) was added, and the contents were heated in a boiling water bath for 5 min. After the colour development, 1 mL of 40% Rochelle salt solution was added when the contents of the tubes were

still warm. The tubes were cooled under a running water tap, and the intensity of the dark red colour was read at 510 nm.

2.3. Impact of pesticides on soil enzymes

The soil enzymatic activities chosen for assay were: invertase (3.2.1.26), acid phosphatase (EC 3.1. 3.2), alkaline phosphatase (E.C. 3. I. 3.1), urease (EC 3.5.1.5), cellulase (EC 3.2.1.4) and protease (EC 3.4.21.112).

For the invertase assay, 5 g of soil was mixed with 0.2 mL of toluene and 5 mL of phosphate buffer in 50-mL Erlenmeyer flasks. Following this, 15 mL of an 8% sucrose solution was added, and the flasks were swirled for a few seconds. The flasks were then covered with stoppers and placed in an incubator at 37°C for 24 hours. After the incubation period, the contents of the solutions were passed through filter paper. Subsequently, 1 mL of the filtrate was pipetted into a 50 mL test tube, and 3 mL of DNSA solution (3,5-dinitrosalicylic acid) was added. All tubes were then placed into a boiling water bath for 5 minutes and allowed to cool at room temperature with tap water. Furthermore, the final volume of each solution was adjusted to 50 mL with double-distilled water. The glucose produced was determined colourimetrically at 508 nm and expressed as µg glucose/g of soil (Aswathy et al., 2013).

For phosphatase enzyme, 1 g of dry soil mixed with 4 ml of modified universal buffer (MUB), and 1 ml of 0.115 M p-nitrophenylphosphate solution and incubated for 1 hour at 37ºC in a rotating water bath to determine the acid and alkaline phosphatase activity. After incubation, the samples were treated with 1 ml of 0.5 M $CaCl_2$ and 4 ml of 0.5 M NaOH before being filtered. The absorbance of samples was determined at 405 nm using spectrophotometer. pH 6 of buffer was used for the acid phosphatase and pH 11.0 of buffer was used for the alkaline phosphatase(Adão et al., 2016).

The urease activity was assessed by utilizing 5 g of soil particles, which were mixed with 1 mL of toluene in a 50-mL Erlenmeyer flask and allowed to stand for 15 minutes. Following this, 10 ml of a 10% urea solution and 20 ml of citrate buffer were added to the flask and thoroughly mixed. The flasks were then covered and placed in an incubator set at 37°C for 24 hours. After the incubation period, the contents of the soil solution were filtered through filter paper. Moreover, 3 mL of an aliquot from the filtrate was added to a 50-mL test tube along with 4 mL of sodium phenol solution and 3 mL of sodium hypochlorite solution. The tubes were well-swirled for

mixing, and after 20 minutes, the final volume of each solution was adjusted to 50 mL with distilled water. The released ammonium was measured colorimetrically at 578 nm and expressed as mg NH_4-N produced per gram of soil per 24 h (Aswathy et al., 2013).

For the determination of cellulase activity, 1 g of soil sample was treated with 0.5 mL of 1 % solution of carboxymethylcellulose (CMC) and 15 mL of 2 M acetate buffer (pH 5.5) and incubated at 50° C for 24 h. After the incubation, the contents of the solutions were passed through filter paper. Subsequently, 1 ml of the filtrate was pipetted into a 50 ml test tube, and 3 ml of DNSA solution was added. All tubes were then placed into a boiling water bath for 5 minutes and allowed to cool at room temperature with tap water. Furthermore, the final volume of each solution was adjusted to 50 mL with double-distilled water. The glucose produced was determined colourimetrically at 508 nm and expressed as µg glucose/g of soil (Aswathy et al., 2013).

The protease activity of soil was determined by the method of Ladd and Butler (Ladd and Butler 1972). 1g of soil sample treated with 1% casein in 0.2 M Tris–HCl (pH 8.1) buffer and incubated at 37ºC for 1h. The contents were filtered and protease activity was expressed by tyrosine amino acid released (Różyło and Bohacz 2020).

2.4. Statistical Analysis

All experimental data were expressed as mean ± standard error (SE) with three replicates (n = 3) per treatment. Statistical analysis was performed using SPSS Statistics software. A one-way analysis of variance (ANOVA) was used to determine the effect of pesticide treatments on plant growth parameters (root length, shoot length, number of leaves, root collar diameter, and total branches). Differences among means were considered statistically significant at $p < 0.05$. When significant differences were detected, Tukey's Honest Significant Difference (HSD) post-hoc test was applied for multiple comparisons.

3. Results and discussion

3.1. Physiological and biochemical parameters of mung bean plants

Pesticides can affect plant growth in several ways such as interfering with the development of reproductive organs, reducing growth, and altering the metabolism of important nutrients, which reduces the amount of nutrients available for plant growth. The toxicity of pesticides depends on

numerous variables, including the type and rate of pesticide application, spraying technique, climatic conditions, flora composition, humidity, soil moisture content, pH, texture, and microbial activity. The application of chemical pesticides has been found to harm plant growth and development (Sharma et al., 2015; Sharma et al., 2016; Shahzad et al., 2018). According to previous research, high concentrations of dimethoate reduced root and shoot length growth of mung bean (Pathak et al., 2022). The impact of different pesticides on tomato, okra, and garden egg was also shown to reduce plant yields (Glover-Amengor and Tetteh, 2008).

To determine the impact of pesticides on plant growth, different growth parameters of mung bean including root length, shoot length, number of leaves, root collar diameter, and total branches were measured. Our observations also showed that plant growth was adversely affected by pesticide treatments (Fig. 1). Root length differed significantly among treatments (one-way ANOVA: $F(3,8) = 38.62$, $p < 0.001$). The highest root length was recorded in plants treated with malathion (3.93±0.08 cm), followed by cypermethrin (4.1±0.11 cm) and phorate (4.2±0.20 cm), compared with the control (5.03±0.24 cm). Shoot length was also significantly affected ($F(3,8) = 29.74$, $p < 0.001$), with phorate showing the strongest negative effect (39.33±1.67 cm), followed by malathion (41.56±1.75 cm) and cypermethrin (42.73±0.90 cm), whereas control plants showed the highest shoot length (49.7±1.70 cm).

Leaf number varied significantly across treatments ($F(3,8) = 42.18$, $p < 0.001$), with malathion-treated plants having the lowest number of leaves, followed by phorate and cypermethrin treatments. Root collar diameter also differed significantly among treatment groups ($F(3,8) = 26.35$, $p < 0.001$), measuring 0.66±0.03 cm in phorate-treated plants, 0.65±0.03 cm in cypermethrin-treated plants, and 0.63±0.03 cm in malathion-treated plants, compared to 0.76±0.03 cm in control plants. Total branch number was significantly reduced under pesticide treatments ($F(3,8) = 21.89$, $p < 0.001$), with averages of 1.33±0.33 in malathion, 1.66±0.33 in cypermethrin, and 2.00±0.33 in phorate treatments, compared with 2.66±0.33 in the control (Table 3).

Post-hoc Tukey's HSD test confirmed that all pesticide treatments (phorate, cypermethrin, and malathion) differed significantly from the control ($p < 0.05$). Detailed ANOVA and Tukey's HSD pairwise comparison tables are provided in Supplementary Table S1 and S2. Among the tested pesticides, phorate caused the greatest reduction in shoot and root growth, followed by malathion and cypermethrin. Similar harmful effects of insecticides on plant growth have been reported

previously, including reduced coleoptile and radicle growth in maize and negative growth responses in rice under pesticide exposure (Kilic et al., 2015; Moore and Kroger, 2010; Naha et al., 2020). Variations in root collar diameter and branching patterns further suggest that pesticide exposure alters plant structural development and growth regulation. Overall, these findings confirm that commonly used insecticides can significantly and adversely affect plant growth parameters and may compromise crop productivity.

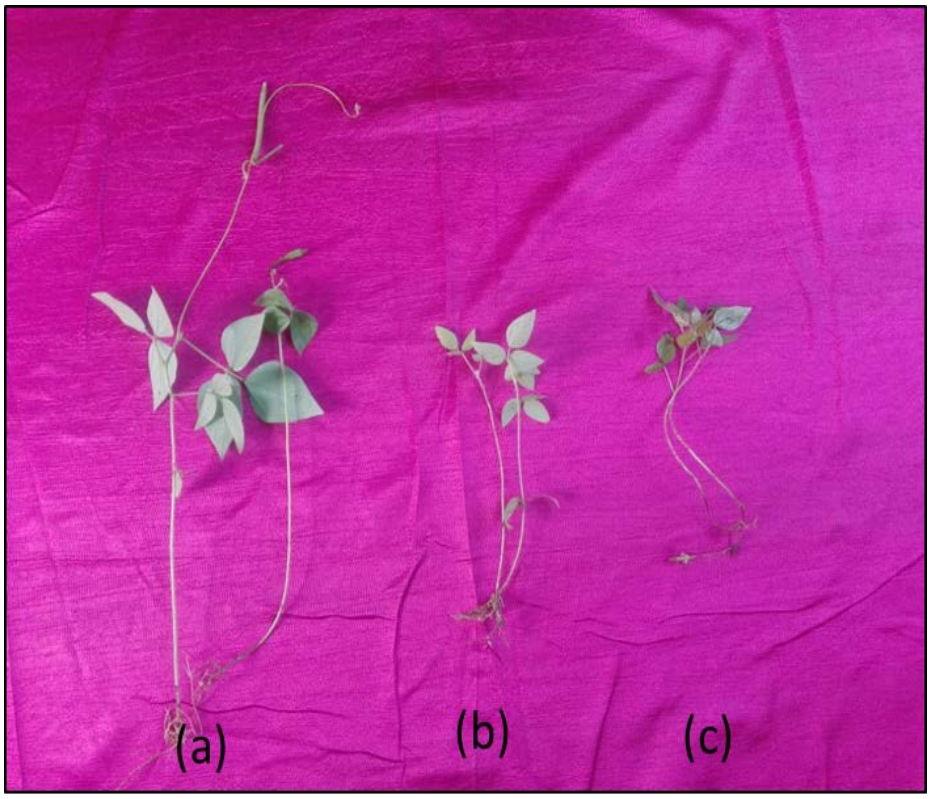

Figure 1: Impact of pesticides on mung bean plants, (a) control, (b) malathion treated plants, (c) phorate treated plants

Table 3: Impact of pesticides on plant growth

Treatment	Root length (cm)	Shoot length (cm)	No. of leaves	Root collar diameter (cm)	Total branch

Control	5.03±0.24	49.7±1.70	9.33±0.33	0.76±0.033	2.66±0.33
Phorate	4.2*±0.20	39.33*±1.67	7.33*±0.33	0.66*±0.033	2*±0.33
Cypermethrin	4.1*±0.11	42.73*±0.90	7.66*±0.33	0.65*±0.03	1.66*±0.33
Malathion	3.93*±0.08	41.56*±1.75	6.66*±0.33	0.63*±0.03	1.33*±0.33

Notes: Values are means±SE, asterisk (*) indicates significant difference ($p \leq 0.05$) as compared to the control

Phenolics are generated and accumulate in the sub-epidermal tissues layers of plants subjected to stress and pathogen attack (Dar et al., 2017). Within a plant tissue the concentration of phenolic compound is dependent on plant physiology, season, age, climate, and can also change at various stages of growth and development (Pratyusha 2022). Numerous internal and external factors impact the synthesis and accumulation of TPC, including as trauma, injury, drought, and pathogen attack (Zahan Akhi et al., 2021).They provide protection and act as protective agents, natural animal toxicants, inhibitors and pesticides against invasive species such as nematodes, herbivores, phytophagous insects, and bacterial and fungal diseases. The Folin-Ciocalteu test was used in our experiment to determine the TPC. The TPC of plants grown in pesticide-treated soil was higher than that of control plants. Total phenolic content of mung bean plants was significantly influenced by pesticide treatments. . Pesticide application increased TPC compared to the control, indicating enhanced secondary metabolite accumulation in response to chemical stress. Among the treatments, phorate showed the highest TPC (1.67 ± 0.04 mg/g *), followed by malathion (1.53 ± 0.02 mg/g *) and cypermethrin (1.34 ± 0.05 mg/g *), whereas the control had the lowest TPC (0.83 ± 0.07 mg/g). All pesticide-treated plants showed statistically significant increases in TPC compared to the control ($p < 0.05$) (Table 4). Dominick and Mohanasundaram (1992) reported that pesticides increased TPC in cotton plants. The application of various pesticides causes stresses in plants, which impair plant growth, which is why our investigation supported these findings

The alterations in a plant's photosynthetic pigments are utilized as a tool to evaluate stressful situations (Ashraf and Harris 2013). The use of pesticides such as pyriprixifen in maize, aldicarb, carbofuran, phorate, fensulsothion and fenamiphos in chickpea, chlorantraniliprole in maize, and difenoconazole and tricyclazole in tomatoes decreased photosynthetic pigments (Kilic et al. 2015, Shakir et al., 2016). Our investigation revealed that pesticides reduced the chlorophyll content in

mung bean plants. The chlorophyll content was Chlorophyll a, Chlorophyll b and total chlorophyll (µg/mL) was measured (fig 2).

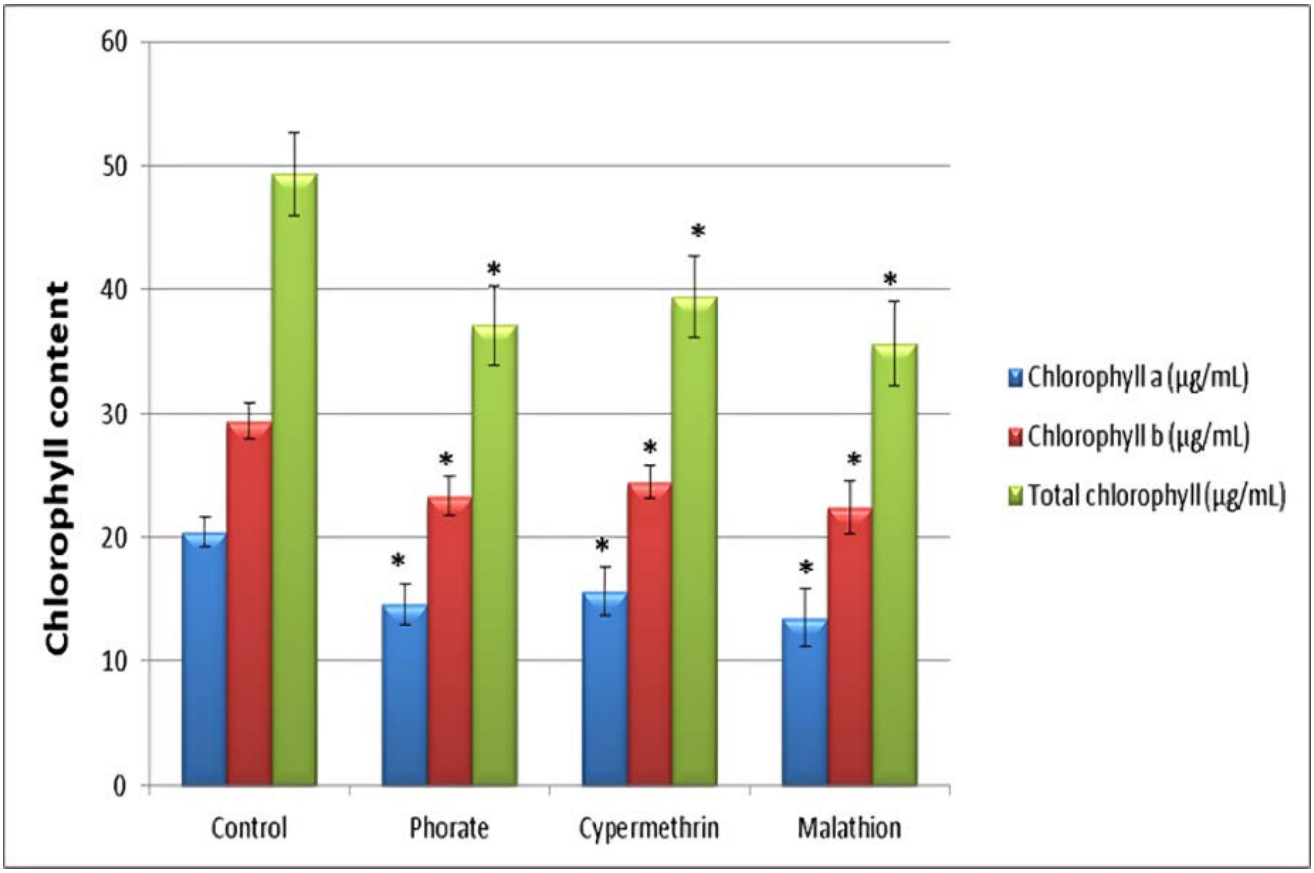

Figure 2: Impact on chlorophyll content in mung bean plants by different pesticides

(Values are means±SE, asterisk (*) indicates significant difference ($p \leq 0.05$) as compared to the control)

Sugar is important in plants because it acts as a food and a key signaling or regulatory molecule that modulate the expression of genes linked to metabolism, growth, development, stress tolerance, and disease resistance. Sugars, both reducing and non-reducing, are essential to the major metabolic pathways and assist in the synthesis of secondary metabolites that improve the plant's medicinal properties (Arsenault et al., 2010, Khatri et al., 2020). In our observation, the most detrimental impact on reducing sugar in plants was observed in malathion treated plants. The 3,5-dinitrosalicylic acid (DNSA) method was used for quantitative estimation of the reducing sugar content. Malathion-treated plants showed the highest reduction in reducing sugar, 24.36 ±1.01

mg/g of fresh weight of plant tissue. After that, reducing sugar 28.36± 0.92 mg/g by phorate and 32.25 ± 1.08 mg/g by cypermethrin was detected in plants (Table 4).

Table 4: Impact on total phenolic content and reducing sugars by pesticides

S. No.	Treatment	Total Phenolic Content (mg/g)	Reducing sugars (mg/g)
1	Control	0.83 ± 0.07	38.47 ± 1.25
2	Phorate	1.67± 0.04*	28.36 ± 0.92*
3	Cypermethrin	1.34± 0.05*	32.25 ± 1.08*
4	Malathion	1.53± 0.02*	24.36 ± 1.01*

Notes: Values are means±SE, asterisk (*) indicates significant difference ($p \leq 0.05$) as compared to the control

3.2. Impact of Pesticides on Soil Enzyme Activities

Invertase enzyme is mainly involved in the carbon cycle in the soil ecosystem and catalyzes the breakdown of polysaccharides into monosaccharides, providing labile carbon and energy sources for soil microorganisms (Zhao et al., 2018). Pesticides are known to reduce soil enzyme activity when applied in excessive amounts, and several studies have reported inhibition even at recommended doses (Ataikiru et al., 2019). In the present study, phorate showed the strongest inhibitory effect on invertase activity, with an observed value of 52.78 µg glucose g^{-1} soil. Cypermethrin-treated soil showed invertase activity of 58.23 µg glucose g^{-1} soil, while malathion-treated soil recorded comparatively higher activity of 60.23 µg glucose g^{-1} soil (fig 3). The stronger suppression of invertase by phorate indicates its greater inhibitory effect on microbial enzymatic processes compared to cypermethrin and malathion. The reduction in invertase activity may be attributed to toxic effects on microbial cells, reduced glucose availability, and lower extracellular enzyme production due to microbial mortality (Anigboro & Tonukari, 2008). Similar inhibitory effects on invertase activity following repeated pesticide application have also been reported by Madella and Kadiyala (2013).

Phosphatase is a key enzyme involved in phosphorus cycling by catalyzing the release of inorganic phosphorus from organically bound forms in soil. Several studies have reported unchanged or reduced phosphatase activity following pesticide application (Kalam et al., 2004; Yan et al., 2011). Filimon et al. (2015) also observed reduced phosphatase activity after the application of cypermethrin and thiamethoxam at field-recommended rates, while other studies reported both stimulatory and inhibitory effects depending on pesticide type and dose (Defo et al., 2011; Jastrzebska, 2011; Micuti et al., 2018). In the present experiment, both acid and alkaline phosphatase activities were reduced by chemical pesticides. Malathion caused the greatest decline in acid phosphatase activity (21.02 µg nitrophenol g^{-1} soil), followed by phorate (24.12 µg nitrophenol g^{-1} soil) and cypermethrin (26.09 µg nitrophenol g^{-1} soil) (fig 3). A similar trend was observed for alkaline phosphatase activity, where malathion-treated soil showed the lowest activity (31.08 µg nitrophenol g^{-1} soil), followed by phorate (33.09 µg nitrophenol g^{-1} soil) and cypermethrin (36.23 µg nitrophenol g^{-1} soil) (fig 3).

Urease plays an essential role in the nitrogen cycle by hydrolyzing urea into ammonia and carbon dioxide and regulating nitrogen availability for plant uptake (Makoi & Ndakidemi, 2008; Xie et al., 2014). Previous studies have reported that pesticide application can either reduce or have no effect on urease activity (Tejada et al., 2009; Tejada et al., 2011; Yan et al., 2011; Bacmaga et al., 2012). In the present study, urease activity was negatively affected by chemical pesticides. Malathion-treated soil showed the lowest urease activity (67.09 µg ammonia g^{-1} soil), followed by phorate-treated soil (71.09 µg ammonia g^{-1} soil), whereas cypermethrin-treated soil recorded comparatively higher activity (76.09 µg ammonia g^{-1} soil) (fig 3).

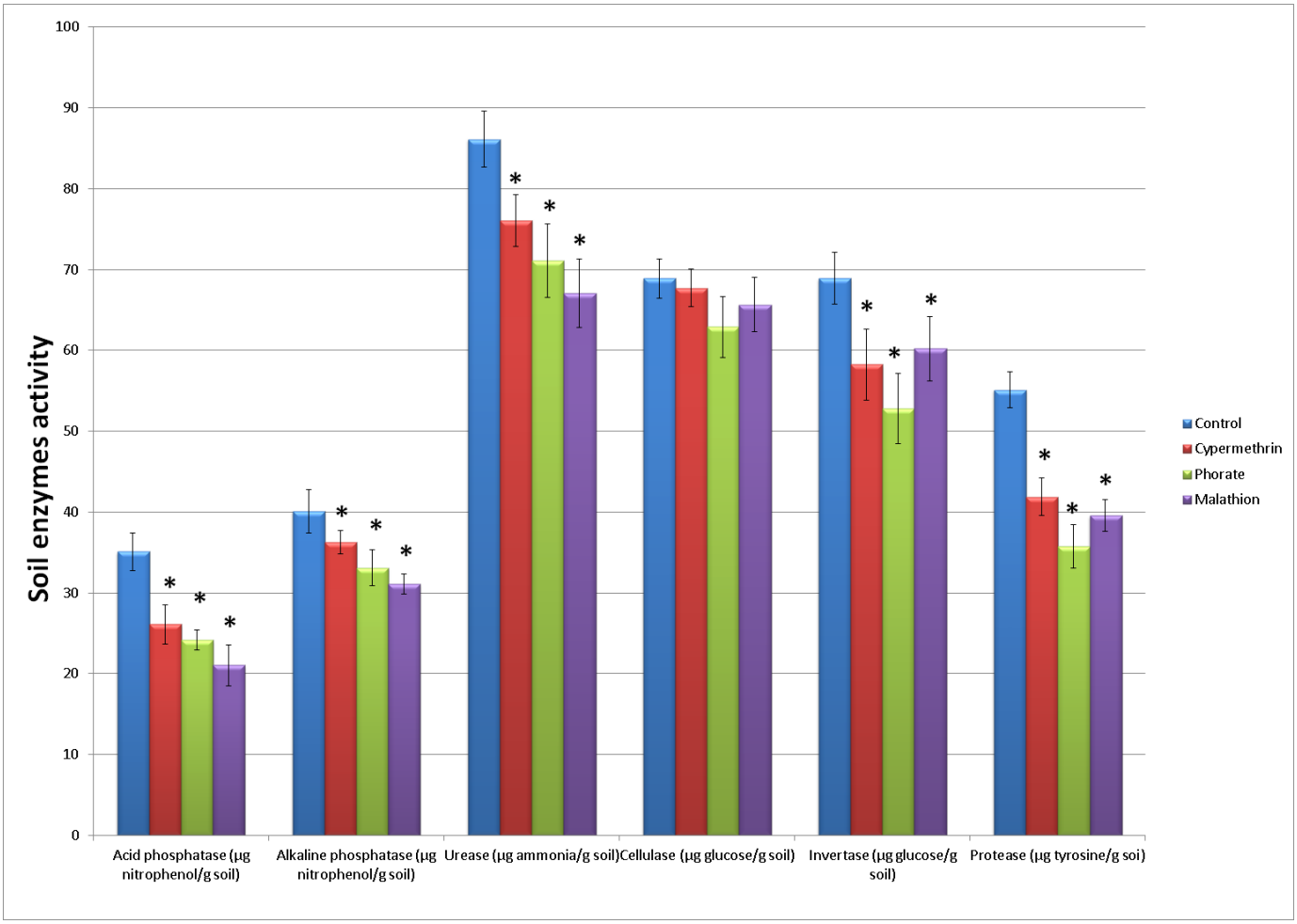

Figure 3: Impact different pesticides on soil enzymes activity (Values are means±SE, asterisk (*) indicates significant difference ($p \leq 0.05$) as compared to the control))

Cellulase enzyme plays an important role in soil organic matter decomposition and carbon turnover. In the present experiment, pesticide application showed minimal impact on cellulase activity. Similar observations were reported by Ramudu et al. (2011), who found that pesticide application did not significantly affect cellulase activity. Cellulase activity remained relatively stable across treatments, with cypermethrin-treated soil showing 67.7 µg glucose g^{-1} soil, phorate-treated soil showing 62.89 µg glucose g^{-1} soil, and malathion-treated soil recording 65.65 µg glucose g^{-1} soil (fig 3).

Protease enzymes are involved in nitrogen cycling by breaking down proteins into polypeptides and amino acids (Dhillon et al., 2017). Ataikiru et al. (2019) reported reduced protease activity

following carbofuran and paraquat application, while Maddela and Venkateswarlu (2018) observed that low pesticide doses could stimulate protease activity, with higher doses causing inhibition. In the present study, phorate-treated soil showed the lowest protease activity (35.76 µg tyrosine g^{-1} soil), followed by malathion-treated soil (39.56 µg tyrosine g^{-1} soil), whereas cypermethrin-treated soil exhibited the highest protease activity among the tested pesticides (41.87 µg tyrosine g^{-1} soil) (fig 3).

4. Conclusions

Chemical pesticides affect plant growth, soil health, and the whole environment. Pesticides disrupt the biological processes of the biological system and lead to several diseases. Even at their field-recommended dosages, we have observed in our experiment that they adversely impair plant growth. These chemical pesticides also harm soil health. Soil enzymes play a crucial role in the soil ecosystem by catalyzing several essential activities and maintaining soil health. Pesticides impact soil health by altering the activity of soil enzymes. According to our experiment, compared to cypermethrin, we can say that malathion and phorate have the most negative effects on plant growth and soil enzyme activities.

Authors' contribution

NU was involved in the writing, editing, analyzing, interpreting data, and table preparation, and AS was the mentor and involved in manuscript writing and editing

Conflicts of Interest

The authors declare no conflict of interest.

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