Pesticide species intake transport phenomenon from droplet to plant body

An internship report submitted

By

Sayantan Pramanick
and
Abhilasha

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National Institute of Technology Durgapur, West Bengal, India

Microfluidics and Microscale Transport Processes Laboratory,

Department of Mechanical Engineering

Indian Institute of Technology Guwahati, Assam, India

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DECLARATION

Report Title: **Pesticide species intake transport phenomenon through droplet to plant body**

We declare that the presented internship report represents largely our and our supervisor's ideas and work in our own words. Where others ideas or words have been included, we have adequately cited and listed in the reference materials. The report has been prepared without resorting to plagiarism. We have adhered to all principles of academic honesty and integrity. No falsified or fabricated data have been presented in the thesis. We understand that any violation of the above will cause for disciplinary action by the institute, including revoking the conferred degree, if conferred, and can also evoke penal action from the sources which have not been properly cited or from whom proper permission has not been taken.

Sayantan Pramanick and Abhilasha

Date: 10^{th} July,2025

CERTIFICATE

It is certified that the work contained in this internship report entitled **"Pesticide species intake transport phenomenon through droplet to plant body"** submitted by **Sayantan Pramanick and Abhilasha**, B-Tech. student from the Department of Mechanical Engineering , National Institute of Technology Durgapur, Durgapur, Roll number**: 23ME8055 and 23ME8040**, for internship is absolutely based on their own work carried out under our supervision and that this work/thesis has not been submitted elsewhere for any degree.

Dr. Pranab Kumar Mondal
(Project supervisor)
Associate Professor
Department of Mechanical Engineering
IIT Guwahati

Date: 10th July 2025

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Sayantan Pramanick and Abhilasha

ABSTRACT

In this present study, we investigated the intake transport phenomena of pesticide species in the Moong plant body utilizing droplet evaporation dynamics in a Goniometer. Different concentration of pesticide droplet was applied to the leaves of three different aged plants in order to investigate pesticide droplet features and uptake time. The water potential of the leaf was assessed in order to estimate the pressure gradient. The water content and porosity of leaf, stem, and root were assessed in order to create an experimentally based 3D numerical model of pesticide intake in plant body. Pesticide droplet evaporation duration was significantly reduced in high concentration pesticide droplets. Water potential and content vary depending on the age of the plant. The porosity of various plant body components was larger in 40-day-old plants, which had a major impact on increased pesticide intake from leaf to stem. Pesticide droplet intake velocity was high at higher concentrations, which was aided by the older plant's porous structure. Numerical modelling demonstrated that pesticide absorption is mostly determined by concentration and porosity of plant body. In order to reduce contamination-free crop production, less concentrated pesticide application is strongly recommended. Another major finding of the current study is that pesticide residue is present in plant body parts following droplet evaporation, regardless of concentration, porosity and age. It was suggested that using environmentally friendly organic pesticides for pesticide-free food production in the future would be far superior for sustainable agriculture practices without jeopardizing global food security.

Keywords: Pesticides, Moong beans, Droplet evaporation, Water potential, Porosity, Numerical simulation, Pesticide species transport, Healthier food.

1.Introduction

Modern agriculture practices rely heavily on the use of several types of chemical pesticides to combat diverse pathogenic attacks on crop plants. However, increased usage of toxic pesticides leads to contaminated agricultural products. In light of pesticide contamination, food safety has become a significant concern for the vast majority of the world's population. Different pesticides are concentrated in various body parts of the crop plants. Pesticides with highly electronegative atoms are readily absorbed in plant (J. Liu et al. 2023). The uptake and dispersion of pesticides in edible vegetables has been shown to have an impact on human health. Crop-specific pesticide intake modelling has advanced, allowing for the estimation of pesticide residue in the environment following foliar spray application, as well as the percentage ingested by humans (Fantke et al. 2011). Selecting the most appropriate method of pesticide application helps to reduce hazardous pesticide consumption, allowing for food security in pesticide-dependent farming.

The penetration of pesticides into plant leaves is primarily determined by the physiochemical properties of the active components, specifically molecular size and lipophilicity. Pesticide absorption by leaves is dependent on soil moisture content, so it is important to pay attention to it while spraying pesticides on them. Soil moisture content influences stomatal opening and shutting, as well as leaf water potential (Zhou et al. 2024). A better understanding of foliar uptake process leads to more rational use of pesticide and reduce its negative impact on environment (C. J. Wang and Liu 2007). Pesticide uptake in Chinese cabbage roots follows this order: fenbuconazole > avermectin > thiamethoxam > spirotetrama (W. Wang et al. 2019). Pathogenic fungi found in edible parts were commonly treated with triazole pesticides. The absorption of the three triazole insecticides in plant tissues varied. The order of pesticide uptake in rice roots is epoxiconazole > tebuconazole > triadimefon, which reverses in rice shoots. The study of pesticide uptake in food crops contributes to safety of food products (H. Li et al., 2022). Plant uptake of pesticide residue can be measured by using various parameters, such as pesticide mobility within soil, plant transpiration stream, root soil transfer rate, plant growth (Hwang, Lee, and Kim 2017). Understanding the concept that, how crops take up and translocate pesticide, is an important factor to predict the pesticide accumulation in agricultural products.

To investigate the interaction between pesticide and bionic surface, a host-guest gating system was integrated into artificial porous surfaces to create the bionic stomatal surface. This method of pesticide transport on bionic surfaces is beneficial since it aids in the elimination of pesticide residues from the environment (G. Li et al. 2024). The pressure-chamber technique was effective for studying pesticide uptake and translocation since it does not affect the root system. Some plant species (e.g., sugarcane) absorb pesticides from the soil in which they are produced, that is a significant element in determining the destination of pesticides in the environment (ZachariaKishimba and Masahiko 2010).

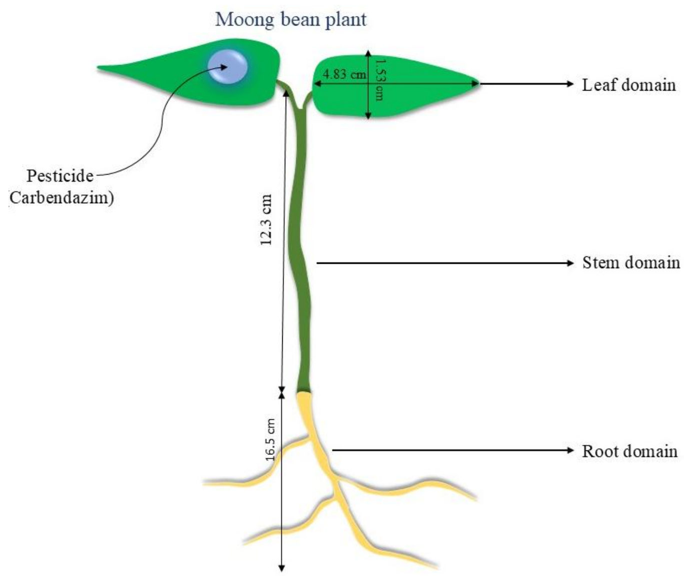

Figure 1: Schematic diagram of moong plant

The three best pesticide application methods (i.e., drip irrigation, foliar spray, and broadcast application) were selected for modelling simulation. Drip irrigation produces higher application efficiency for pesticide compared to other methods. It concerns food safety problems due to pesticide residue because of high level efficiency (X. Zhang and Li 2023).The extent of plant uptake can be estimated theoretically by using a mathematical model. The dynamic model approach was useful for implementing the appearance and growth of individual fruits. This approach was useful for assuming constant plant mass and transpiration, where growth dilution is described by rate constants (Rein et al. 2024). Wheat plants were used as a model to investigate this notion in a hydroponic system as a function of time over 144 hours. The pesticides' time-dependent uptake kinetics were modelled using a first-order 1-compartment kinetic model. Root lipid content was a key criterion in understanding the relationship between RCF and Kow for pesticides in several plant species (Q. Liu et al. 2021). The symplastic pathway was used to absorb hydrophilic pesticides, while the apoplastic pathway was used for lipophilic pesticides. Pesticides with greater log Kow and lower Sw accumulate more easily in roots, while pesticides with lower log Kow and higher Sw are more likely to be translocated from roots to shoots (F. Wang et al. 2021). These models rely on pesticide doses and lipophilicity (Turgut 2005). The act of metabolizing pesticides is an essential step in producing cleaner crops that contain less pesticide. The acquired mechanistic insights into pesticide metabolic pathways allow for more efficient pesticide breakdown (J. J. Zhang and Yang 2021). Pesticide residues are most typically found in leguminous plants; however, no modelling methods predict residue concentrations in edible legume seeds with high protein content.

Considering the significance of the research, in this present study, we have analyzed the intake transport phenomenon of pesticide species in Moong plant body by analysing the change of droplet size of different concentration in regular time interval. In addition, using different experimental results we have develop a novel computational model of pesticide intake in plant body. Outcomes of this work will enlighten our knowledge on the action of intake transport phenomenon of pesticide species in plant body as a practical application of microfluidics in modern agriculture system for healthier food supply in future.

2.Materials and Method

2.1Materials

Moong Seeds (K-851), Petry plates, Filter Paper, DI water, feeding tubes, 4% Sodium Hypochlorite (for sterilization), Plastic pot, Soil, Pesticide (HI field -AG 500gm, Carbostin 2-3g/l, Carbendazim 50% WP), Spinning machine, Brush, Ethanol, Centrifuge Tube, Glutaraldehyde, Sucrose, Methylene blue, Analytical balance, Vortex, Measuring cylinder, Rack, Tissue paper, Thermometer, Stop watch, Forceps, Blade, Scissor, Filter, Syringe, Abdos test tube.

2.2Seed germination and growth

Moong seeds (*Vagina radiata*, K-851) were taken in a beaker for sterilization within a laminar airflow chamber. Seeds were sterilized with 4% sodium hypochlorite solution for 10 minutes following regular germination procedure of our lab. After that, DI water was added to it and rinsed well using a micropipette for 2-3 minutes. The seeds were then thoroughly washed with DI water for five minutes. To ensure the proper removal of chemical residues and for the proper germination of seeds, this process was done five times. Seeds were then placed in a petri plate containing moist filter paper. The seeds were arranged in a 3×3 pattern that ensures proper spacing between them for growth. For germination, these seed plates were kept in a germination chamber under a dark cycle, which is set to 26°C and 75% relative humidity for 36 hours.

Figure 2: Seed germination and plantation of moong bean seedling

2.3 Plant preparation

A small plastic pot of height 7 cm and outer diameter 5.7cm was taken for controlled plant growth in dedicated chamber. We take 125 gm soil for each pot. After germinated young seedlings were planted properly in prepared pots. These seedlings were then kept in a plant growth chamber for 15 days for proper leaf growth. Then entire experiment was carried out on 15,30- and 40-days old plant During entire experimental period we maintained 26°C temperature and 75% relative humidity and under 12hr day light cycle.

2.4 Pesticide preparation

Three samples of various pesticide concentrations were prepared. The concentrations are 0, 0.5, and 3 g/l. In 0g/l, there is no pesticide present, simply DI water. The different pesticide solutions were prepared using 10ml of DI water. After adding pesticide in DI water, the solution was vortexed for 2-3 minutes in order to proper dissolve of pesticide residue in DI water. Now the prepared solution was ready for droplet evaporation study.

2.5 Pesticide droplet evaporation test

A dedicated Goniometer setup was used to evaluate pesticide droplet evaporation on moong bean leaves. Evaporation of three prepared pesticide solutions (0.5 and 3g/l) along with controlled solution (0g/l) were used for the present study. The plant was placed properly in the goniometer chamber in such a way that the leaf surface is flat so that it's easy to place the droplet on the leaf. Three microliter droplet was added on the leaf surface by using micropipette. Droplet evaporation time was pictorially recorded in 30s interval. Both initial and after the experiment humidity and temperature was noted. In order to maintain the humidity constant temperature (25℃) was maintained in the chamber. Droplet evaporation test for each solution was repeated thrice for higher reproducibility of result.

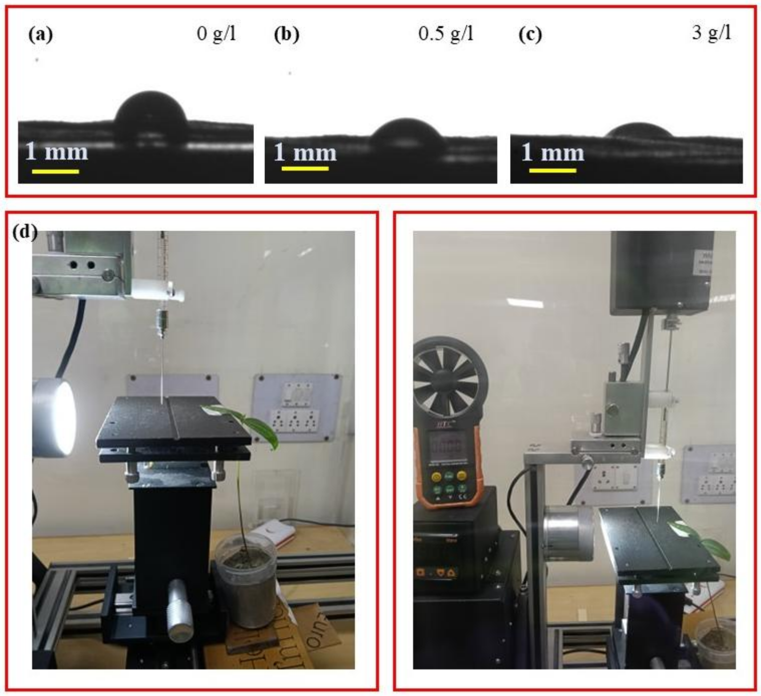

Figure 3: Pictorial demonstration of droplet size of varied concentration of pesticides after 10 minutes. (a) 0g/l, (b) 0.5g/l and (c) 3g/l. (d) setup of droplet evaporation test within goniometer chamber

2.6 Water Potential Measurement of Leaf

The water potential of a leaf was determined using the Chardakov method (Gibson, Richards Donà, and Smith 2023). In this method, leaf is immersed usually in a sucrose solution of known concentration. Sucrose solution of different concentration i.e.0.1M, 0.2M, 0.3M, 0.4M and 0.5M were prepared. 50ml distilled water was used for solution preparation. For 0.1M concentration, 1.71g sucrose were mixed in 50ml distilled water, similarly other concentration of sucrose solution was also prepared. Prepared solutions were mixed using vortex and two sets of solution was made namely A and B. In set A we put the leaves and kept it for 30 minutes in solution. After that we remove the leaf from solution and measured its temperature, this process we repeated for every concentration. In set B methylene blue colour was added as an indicator. Then we put a drop of methylene blue solution in set A. Followed by movement of the methylene blue droplet was observed. We used following formula to calculate the water potential with reference to observed isotonic solution

Then formula; $\psi_w = -iCRT$,here ψ_w is water potential of leaf, i is the Van't Hoff factor of sucrose, C is the molar concentration of sucrose, R is the universal constant and T is the temperature of that solution.

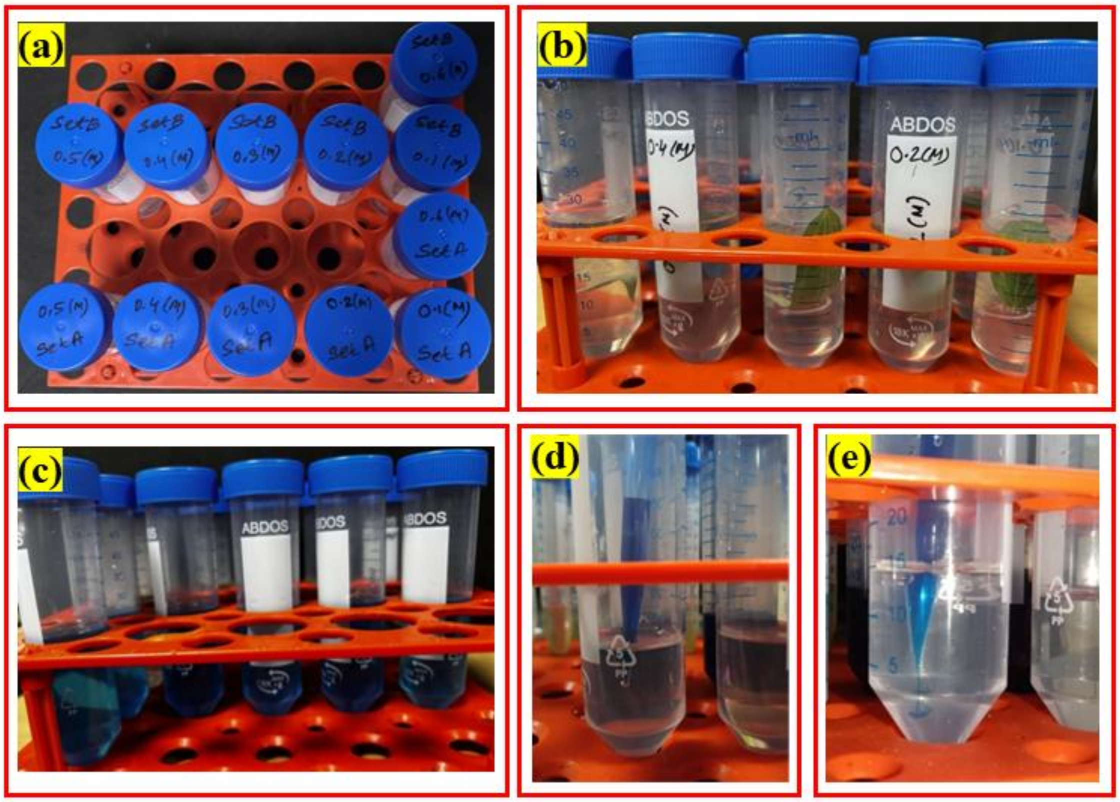

Figure 4: Pictorial presentation of water potential measurement of leaf. (a) Set A and B of sucrose solution, (b) Set A with immersed leaf, (c) Methylene blue solution, (d) and (e) represent the methylene blue droplet addition into the set A after removal of immersed leaf from sucrose solution.

2.7 Water Content Measurement plant body parts

Water content is defined as the fraction of the difference between the wet and dry weights of a substance divided by its wet weight. The water content of the leaf, stem, and root was determined by cutting them into separate pieces, weighing each one, and recording the wet weight. Then samples were then allowed to dry fully for 24 hours in a hot air oven and dry weight was measured for each sample individually.

2.8 Porosity measurement of different plant body parts

Scanning electron microscopy was used to measure the porosity of different body parts of moong bean plant. We performed (SEM) of leaf, stem, and root sections of three different aged plants (15, 30 and 40 days). Thin transverse sections of stem and root was prepared. For leaf we carefully isolate the upper layer of the leaf. For tissue fixation of the prepared samples 40% glutaraldehyde was used. During dehydration of samples different concentration (30%, 70%, and 100%) of ethanol was taken. After dehydration samples were gold coated and porosity was observed under scanning electron microscope. Porosity is calculated as the fraction of the sum of all areas of small pores of the selected domain to the area of the selected domain.

2.9. Mathematical modelling and numerical methodology

Equation of species transport through porous media

$$\varepsilon_{\mathrm{p}} \frac{\partial \mathrm{c}}{\partial \mathrm{t}} + \nabla \cdot \mathbf{J} + \mathbf{u} \cdot \nabla \mathrm{c} = 0 \tag{1a}$$

$$\mathbf{J} = -\left(\theta \mathrm{D}_{e}\right) \nabla \mathrm{c} \tag{1b}$$

$$\mathrm{D}_{\mathrm{e}} = \frac{\varepsilon_{\mathrm{p}}}{\tau_{\mathrm{F}}} \mathrm{D}_{\mathrm{F}} \tag{1c}$$

$$\tau_{\mathrm{F}} = \varepsilon_{\mathrm{p}}^{-\frac{1}{3}} \tag{1d}$$

Here, D_{e}, θ and τ_{F} denotes effective diffusion coefficient, water content and tortuosity respectively

Porous medium equation of flow field

$$\nabla \cdot \mathbf{u} = 0 \tag{2}$$

$$\frac{1}{\varepsilon_{p}} \rho \frac{\partial \mathbf{u}}{\partial t} + \frac{1}{\varepsilon_{p}} \rho (\mathbf{u} \cdot \nabla) \mathbf{u} \frac{1}{\varepsilon_{p}} = \nabla \cdot [-p\mathbf{I} + \mathbf{K}] - \left(\mu \kappa^{-1}\right) \mathbf{u} \tag{3a}$$

$$\mathbf{K} = \mu \frac{1}{\varepsilon_{p}} \left(\nabla \mathbf{u} + (\nabla \mathbf{u})^{\mathrm{T}}\right) \tag{3b}$$

Permeability of porous plant body is estimated from kozeny-carman model

$$\kappa = \frac{\mathrm{d}_{\mathrm{p}}^{2} \varepsilon_{p}^{3}}{180\left(1-\varepsilon_{p}\right)^{2}} \tag{4}$$

Here d_p is the pore size of different domains of plant like leaf, stem and root to calculate the value of d_p we have performed the SEM imaging of leaf, stem and root cross-sections with different age of moong plant.

We used COMSOL Multiphysics software for numerical simulation of pesticide species transport utilizing 3D geometry of original experimented moong plants.

3 Results and discussions

3.1 Dynamics of pesticide droplet evaporation

In this present study we analyse the pesticide droplet evaporation on moong bean plant leaf in a dedicated goniometer chamber. We found that in respect to 0g/l concentration of droplet in higher concentration (3g/l) base radius decrease rapidly, as presented in (Figure 5a). Similarly, droplet height also decreases in speed at 3g/l concentration (Figure 5b). Volume of the droplet is decreasing in higher concentration of pesticide, as depicted in (Figure 5c). Radius of curvature also following the same trend (Figure5d). However, droplet pressure is increasing in higher concentration of pesticide (Figure5e), after observation of droplet characteristics of different concentration of pesticide on moong leaves. We further calculate the total evaporation time or stopping time Figure5f represent the pesticide droplet evaporation time. It showed that droplet evaporation time (33 minutes) is very less in higher concentration rather than lower concentration of pesticide. The unique droplet characteristics with low evaporation time for 3g/l pesticide droplet indicating that due to presence of more amount of ions in high concentrated pesticide droplet it interacts with the environment more rapidly and becomes evaporated in less time.

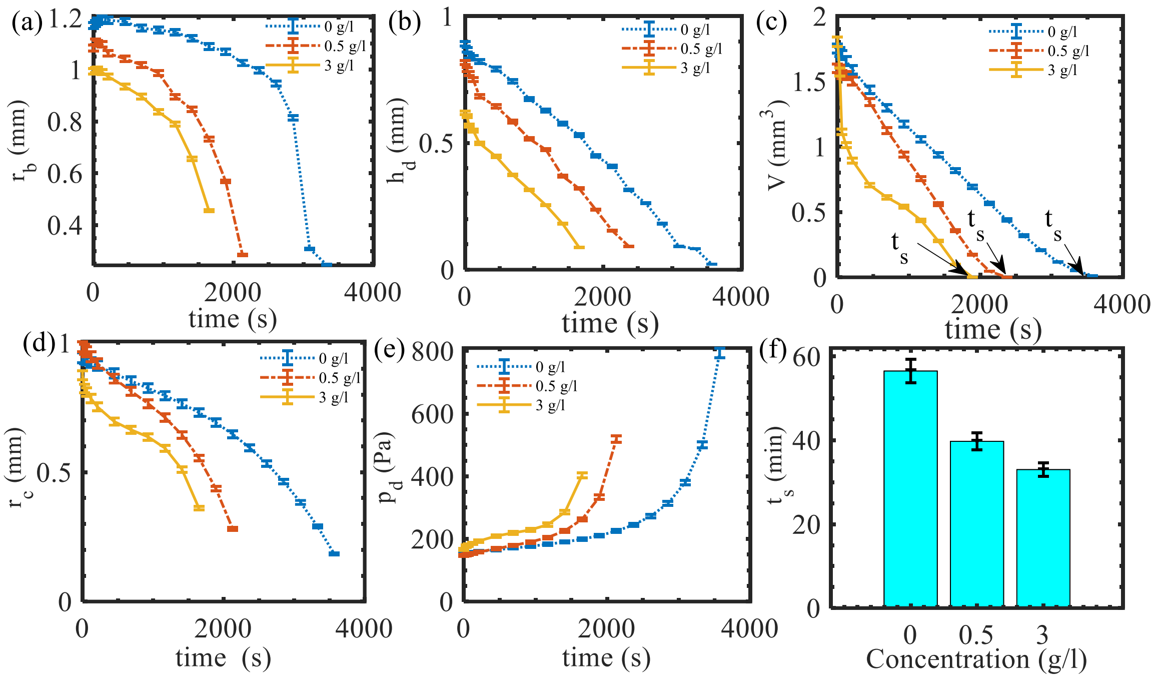

Figure 5: Dynamics of pesticide droplet evaporation with time (a) Base radius of droplet r_b, (b) Height of droplet h_d, (c) Volume of droplet , (d) Change in radius of curvature r_c , (e) Trends in droplet pressure P_d (f) Droplet evaporation or stopping time t_s of pesticide with different concentration.

3.2 Water potential of leaf

Now we calculate the water potential on the basis of osmotic pressure differences.

We observed that in all concentration except 0.4M, there was rise of methylene blue droplet. In 0.4M concentration droplet diffuses Therefore we used 0.4M methylene blue solution as an isotonic solution, we found that water potential of leaf at 15 days ,30days and 40 days is -0.9972MPa, -1.242345 and -1.2465, respectively, as presented in Figure6. (water potential of different aged leaf)

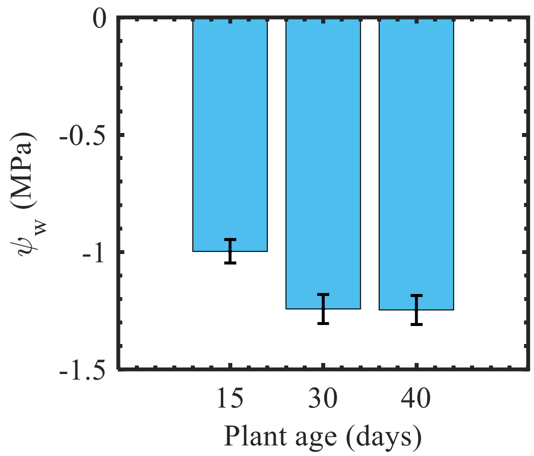

Figure6. water potential of different aged leaf

Higher water potential of 40 days plant leaf is due to higher water transport from root to leaf through mature developed xylem. As plant possess under developed immature xylem with less water transport capacity at young age. And higher porosity in mature plant body parts (see upcoming section 3.4) also accelerate this process.

3.3 Water content of different plant body parts

After 15 days water potential of root and stem is decreased according to the age of the plant (Figure a and b) however water potential of leaf remains almost constant up to 40 days, as presented in (Figure7c). It reveals in order to maintain the constant photosynthetic activity in leaf water is supplied to leaf regularly

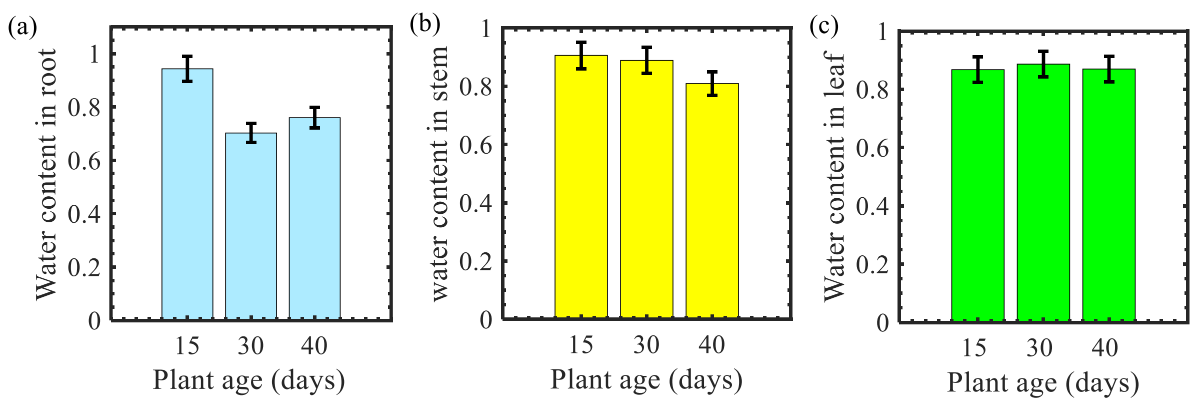

Figure 7: Water content of root (a), stem (b) and leaf (c) in different age interval.

3.4 Porosity of Root, stem and leaf

Now we observed the porosity of 3 different aged root, stem and leaf of moong plant to utilising the numerical modelling of pesticide transport in respective body parts. Figure8, we depicted the SEM images of root, stem and leaf of 15,30- and 40-days aged plants

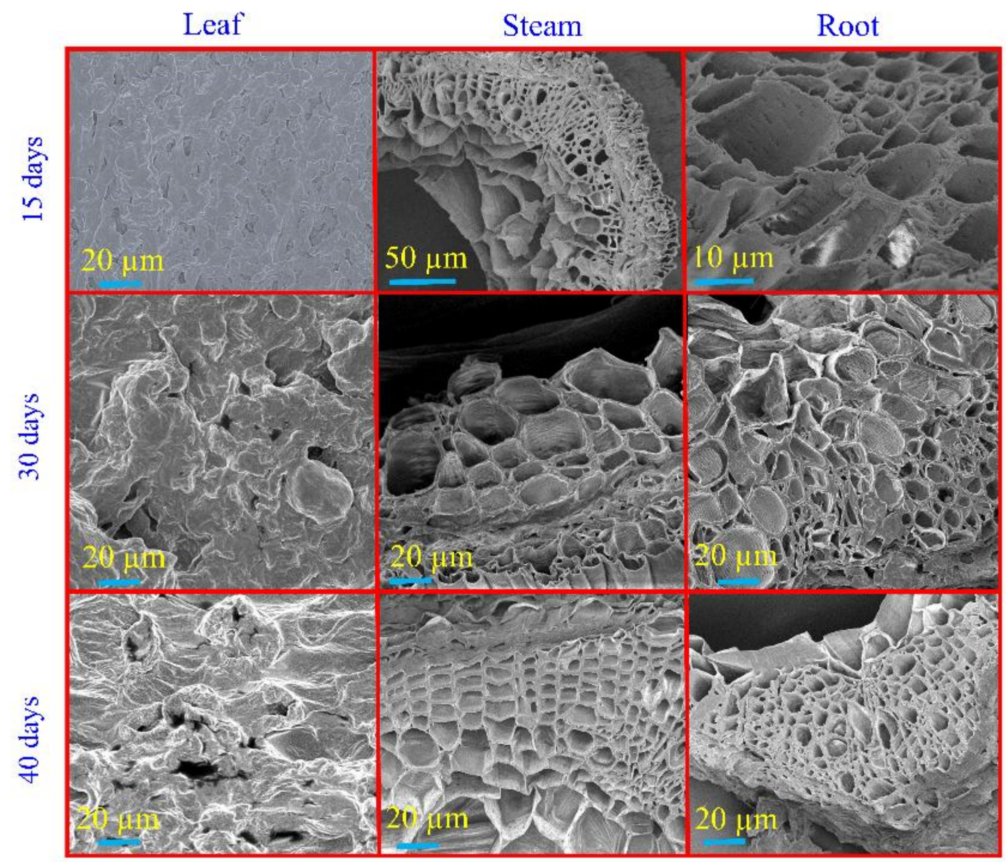

Figure 8: SEM image of leaf, stem and root of 15,30- and 40-days old moong plant

Gaussian distribution plot of mean pore size is presented in Figure 9. The pore diameter of leaf is decreasing with increase in time; however, pore diameter of stem and root has decreased initially and then increased with time

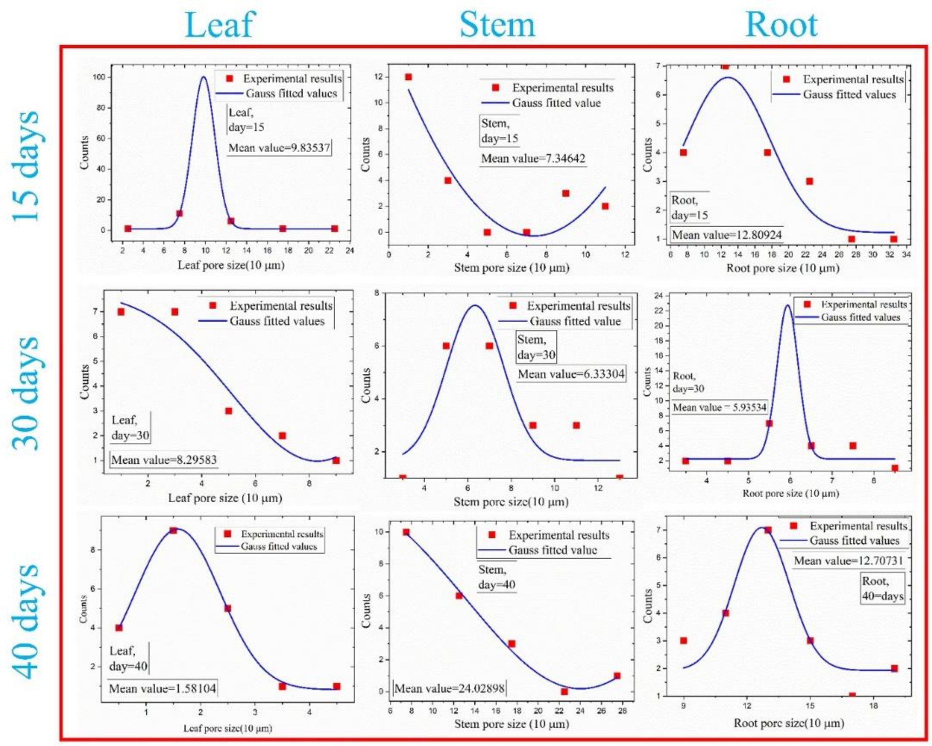

Figure 9: Gaussian Distribution plot for pore size of leaf, stem and root of different aged moong plant

Now we present the porosity of root, stem and leaf in Figure 10a, b and c respectively. Porosity of all three body parts of moong plants increases with age due to maturation of tissues. Mature root and stem is more porous than leaf.

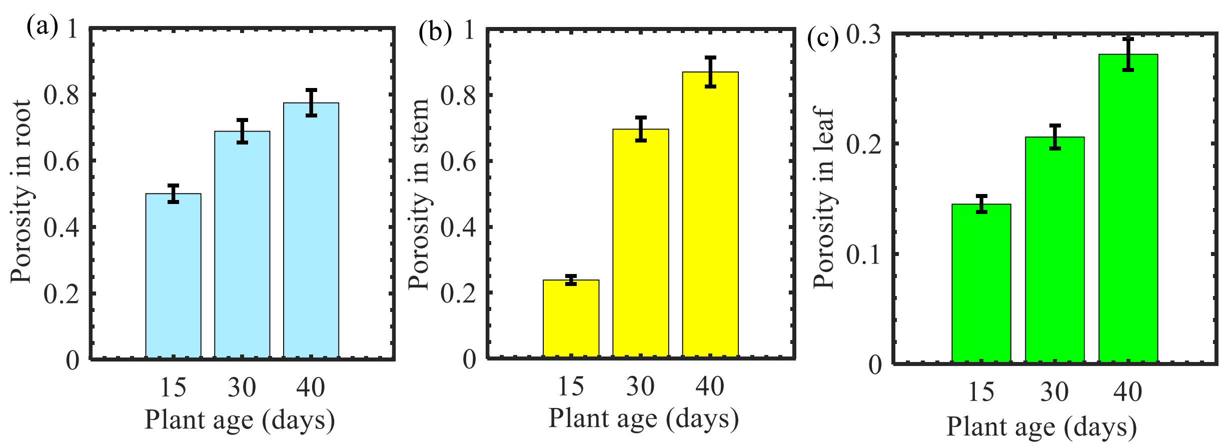

Figure 10 Porosity of root, stem and leaf of moong plant according to the age.

Permeability of root and stem increases in 40 days old mature plants (Figure11a and b) with respect to low permeability of leaf. The low permeability of leaf observes due to less porous structure present in leaf (see Figure 8).

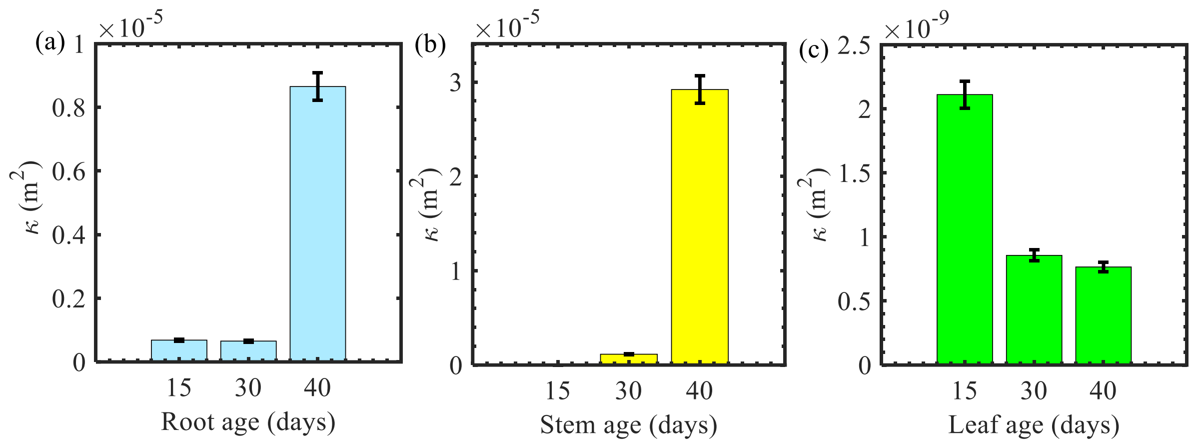

Figure 11: Permeability of leaf, stem and root domain according to kozeny-carman model.

3.5 Pesticide species transport in plant body

Figures 12 and 13 illustrate the significant findings of numerical simulations for pesticide species transport. The contours of the velocity field for pesticide droplet intake revealed that in higher concentrated pesticides, velocity is high toward leaf to shoot transport, as shown in Figure 12, due to low velocity intake of pesticide droplets in lower concentrations requiring a long time. In juvenile stages (15 days), intake velocity is very low due to the less porous structure in the plant body, as opposed to the high porous structure and high intake velocity in higher age moong plants (40 days).

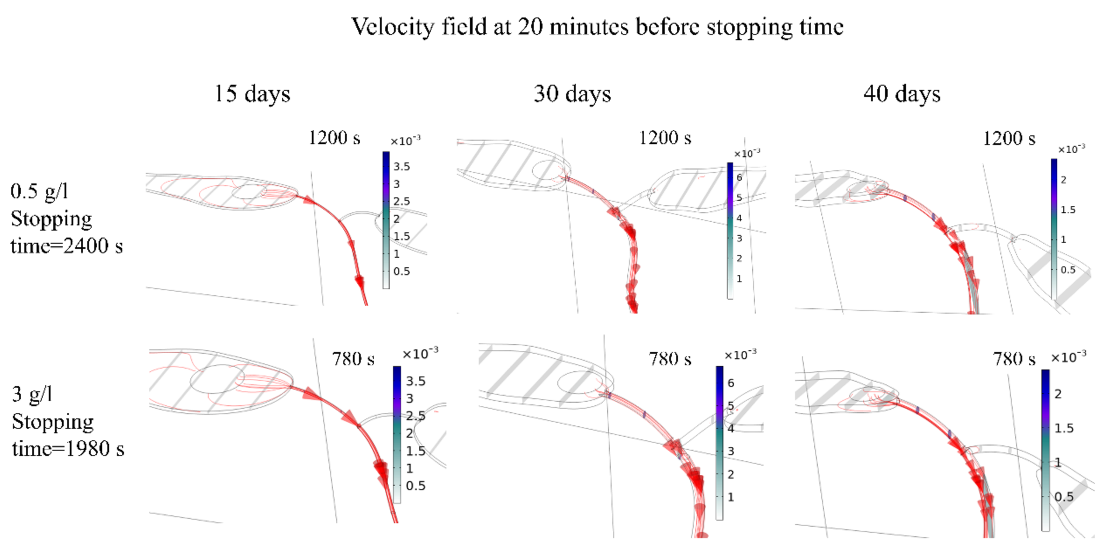

Figure 12: Contours of velocity field at 20 minutes before stopping time of droplet of 0.5 and 3g/l pesticide concentration in different aged plant

Similarly, the contours of the pesticide concentration field are higher in the leaves of young aged plants, while higher concentrations of pesticide were detected in the stems of older aged plants, showing that pesticide uptake from leaf to stem is very high in 3g/l in contrast to 0.5g/l (Figure 13). Overall, the simulation results showed that the intake of pesticides in moong plants was strongly dependent on two main factors: high pesticide concentration and high porosity structure of plant body parts. Another notable finding is that, regardless of pesticide concentration and porosity after droplet evaporation (stopping time), pesticide residue is present in the leaf and stem of moong plants. Using high concentrations of pesticides is extremely hazardous to both crop production and food security, as it contaminates the plant's body with pesticides. However, using low concentrations of pesticides results in less residue. Based on the findings of this study, it is recommended that environmentally friendly organic pesticides be used for farming worldwide in order to promote sustainable agricultural development.

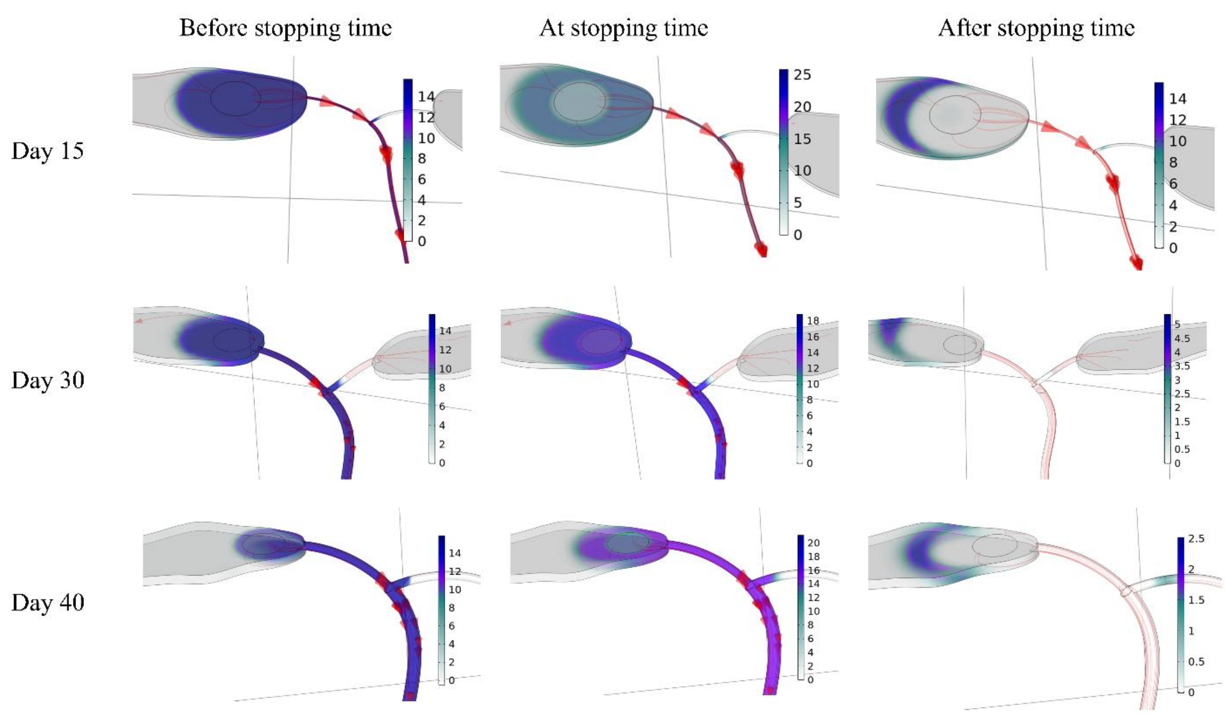

Figure 13: concentration field of pesticide before, at and after evaporation time (stopping time) in different aged moong plant

Conclusion

Present study, explored the pesticide droplet evaporation dynamics and intake in Moong bean plant using goniometer and numerical modelling. We found that in higher concentration pesticide evaporation and intake from leaf to stem is very faster than low concentrated pesticide droplet. In addition, porosity has significant impact on pesticide intake in plant. Use of low concentrated chemical pesticide is highly recommended to produce less contamination free crop plants. As pesticide residue presents in plant body parts without depending upon concentration and porosity. It is better to use organic pesticide for contamination free food supply in future.The current study explored pesticide droplet evaporation dynamics and uptake in Moong bean plants using goniometer and numerical modelling. We found that greater concentration pesticide evaporation and absorption from leaf to stem occur much faster than lower concentration pesticide droplets. Furthermore, porosity has a major effect on pesticide uptake in plants. It is strongly advised to use low concentration chemical pesticides in order to grow crop plants with minimal pesticide contamination. Pesticide residue is present in plant body parts regardless of concentration and porosity. It is preferable to utilize organic pesticides for a contamination-free food supply in the future.

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