RESEARCH | Egyptian Journal of Agricultural Research | PLANT PROTECTION

Residual toxicity of Methomyl and γ-Cyhalothrin against Papaya mealybugs on Cassava Leaves

Elena B. Lozano[1,2,3] *, Jake Joshua C. Garces*[1,4*] *and Erlinda A. Vasquez*[3]

Address

[1]*College of Computing, Artificial Intelligence, and Sciences (CCAIS), Cebu Normal University, Osmeña Boulevard, Cebu City, Philippines 6000*

[2]*College of Agriculture and Food Sciences, Department of Pest Management, Visayas State University, Baybay City, Leyte 6521-A; erlinda.vasquez@vsu.ph*

[3]*PhilRootCrops, Philippine Root Crop Research and Training Center, Visayas State University, Baybay City, Leyte 6521-A*

[4]*Education for Sustainable Development (ESD), Cebu Normal University, Osmeña Boulevard, Cebu City, Philippines 6000*

*Corresponding Author: **Jake Joshua C. Garces**, e-mail**:** garcesjj@cnu.edu.ph

Received: 12-05-2023 **; Accepted:** 10-09-2023 **; Published:** 18-04-2024 **DOI:** 10.21608/EJAR.2023.210536.1404

ABSTRACT

Paracoccos marginatus Williams and Granara de Willink (P. *marginatus* or papaya mealybugs [PMBs]*)* is responsible for 75% of the estimated economic loss in cassava growing worldwide. Insecticidal formulations have the ability to manage P. *marginatus* by deteriorating its wax coats to death; nevertheless, it has received little attention in the the tropical setting. In the present study, we investigated the residual toxicity of methomyl and γ- cyhalothrin against papaya mealybugs (PMBs) (*Paracoccos marginatus*) in cassava (*Manihut esculenta*) leaves and determined what stage in the PMB's life cycle the pest is killed by the chemical. Using the label recommendation rate, each insecticide was sprayed onto the surface of healthy leaves of cassava plants. Leaf samples were taken after a period of 2 days from a previously sprayed cassava plant. Using leaf dipping bioassay, cassava leaf samples were cut into circular disc and placed in petri dish lined with wet filter paper, and 20 crawlers, 20 pre-adults, and 20 adult PMBs were introduced into each dish.. The The preparation was under controlled conditions of temperature, relative humidity and photoperiod (25°C; 80% RH; 12h light: 12h dark) in the laboratory and the number of dead insects was recorded. Each group was replicated in three replicates for each stage of the pest's life and for each insecticide tested. Results showed that crawlers were the most susceptible to both insecticides studied. For the residual toxicity test, the half- life of methomyl is 5.1 days while that of γ-cyhalothrin is 4.7 days. These findings suggest that farmers have to wait 5.1 and 4.7 days, respectively for their next spray application schedule. Furthermore, as part of food safety measures, when fresh cassava leaves are used as human food and animal feed, the waiting time for the insecticides to dissipate from the leaf surface is the same as previously stated.

Keywords: Agriculture, insecticides, leaf dip bioassay, toxicity test

INTRODUCTION

The first of the eight millennium development goals (MGDs), the United Nations Sustainable Development Goals (SDG 1=Zero Hunger) and the Philippine Department of Agriculture- Philippine Bureau of Agricultural Research (DA-BAR) focuse on ending hunger (Doyle *et al.,* 2014; Lomazzi *et al.,* 2014; DA-BAR, 2020). These goals are essential to maximize the potential of developing countries to produce economically important crops for human consumption. Cassava (*Manihut esculenta* Crantz) is one of the most important agricultural crops generally cultivated throughout the Philippines as a staple food for more than 15 million Filipinos (DA-BAR, 2016). It is considered a buffer food by many Filipinos for it is a famine resource crop when there is a shortage of supplies of grains such as rice and corn. (Altoveros *et al.,* 2007). Lately, the food for the poor is now a valuable cash crop with many other uses such as raw material for food and non-food products like animal feeds, ethanol, and tapioca (Sayre, 2022). Cassava production in the Philippines, from 2011-2016, amounted to approximately 2.76 million metric tons (DA-BAR, 2016; Statista, 2020). Economically, cassava production is a source of livelihood for more than 218,000 Filipino families who are dependent (partially/ fully) on cassava production as a source of income (Roa, 2011; Howeler, 2020; Philippine Cassava Industry Development Roadmap, 2020). The realization of this agricultural initiative helps attain the UNESCO's Sustainable Development Goal (SGD) No. 1 on Zero Hunger in the Philippines and Millennium Sustainable Goals (National Economic Development Authority [NEDA], 2014; Roldan, 2018).

However, one of the serious pests that are a constraint to cassava production is the papaya mealybug (*Paracoccos marginatus*) or PMB. Yield losses to PMB infestation in Brazil reached to as high as 80% (Belloti *et al.,* 2012). In Southeast Asia and India yield loss is 40% (Wyckhuys *et al.,* 2017). In the Philippines, it was reported that beside phytoplasma, the other major contributor to a low cassava production is the high infestation of arthropod pests which includes the spider mite, white flies, and the mealybug complex (Cassava Congress, 2018). The high infestation of these pests will affect not only the tubers but also the quality of starch produced (Vasquez, E.A, personal communication, 2019). Mealybugs are covered with a waxy flour-like covering and are hard to kill pest. They also could hide in protected crevices and their clumped pattern of distribution make many insecticides ineffective (Mani and Shivaju, 2016). Twice the normal dose of the insecticide will be applied to kill the pest because of their waxy covering (Walker *et al.,* 2006). Each time double or triple dose of broad-spectrum insecticide is applied it will not only promote residual toxicity but also pest resistance. Therefore, the overuse of ineffective insecticides in the chemical control of PMB harms the environment with residues left in the air, human health, produce, soil and water. In Ilocos Norte, Philippines, pesticide residues from vegetables such as pepper, tomatoes, pole sitao, cabbage and eggplant sampled directly from the field and in the market were positive for carbamate except for cabbage and sweet potatoes containing residues of organophosphate (Lutap and Atis, 2013). Likewise, in the farming areas of Benguet, 78 soil samples were positive of endosulfan, profenos, chlorpyrifos, cypermethrin and cyhalothrin (Lu, 2010). Excessive use of insecticides was also proven to be toxic to many biological agents. Methomyl, at LC_{50}, were both residually and topically highly toxic to *Catalococcus* hunter, a parasitoid for pepper weevil (Schuster and Thomson, 2011). Both methomyl and permethrin were equally toxic to *Apanteles*, a braconid wasp used for the biological control of destructive caterpillars (Scoy *et al.,* 2013).

PMB is a hot season pest and has the tendency to increase population in a short period of time producing multiple generations in a year and spreading fast to other areas thus causing severe outbreaks (Mani and Shivaraju, 2016). Although Biological control is environmentally safe, it will not guarantee the immediate suppression of the pest. Once outbreaks will occur, insecticides are needed to reduce the pest to manageable level so to allow the natural enemies to work. Insecticides are part in the control of PMB which should include careful application such as using the right dose, the right type and the right timing. Most farmers prefer to use insecticides because they are highly available, easy to use and have a broad-spectrum bioactivity not minding the downside effects of its toxicity to the killing of the natural enemies. In a related study, it was reported that neurotoxic insecticides like γ-cyhalothrin, methidathion and thiamethoxam caused complete mortality of both striped mealybug, *Ferrisia dasylirii* infesting cotton and its predator, *Tenuisvalve notata* at their highest field rate (Barbosa *et al.,* 2018). Further, most farmers practice a wrong procedure of indiscriminately using insecticides where after chemical sprays they do not observe safety waiting period until the next application to happen so the natural enemies are preserved.

In this regard, the objective of this present study is to evaluate the residual toxicity of methomyl and γ-cyhalothrin against papaya mealybug (PMB) (*Paracoccos marginatus*) in cassava (*Manihut esculenta*) leaves. In particular, this study aimed to: (a) determine the half- life of methomyl and γ-cyhalothrin, (b) know how many days the insecticide losses its toxic effect on the surface of cassava leave, and (c) observe proper timing in spray application at the time PMB eggs are hatch, which is essential in determining methomyl and γ-cyhalothrin sensitivity to the crawlers, pre- adults and adults of PMBs. There are limited studies about the residual toxicity of methomyl and lambda-cyhalothrin against PMB infesting cassava leaves, thus this study was conducted. The knowledge derived from this study is also important, as part of IPM strategy of the pest, particularly in determining the number of days when to release biocontrol agents, detecting which life stage of PMB most vulnerable to insecticide control, and determining the time when cassava leaves are safe to eat as vegetables after being spraying.

Pesticides are still the most used method of controlling arthropod plant pests and animal ectoparasites. Pesticides' sublethal impacts on insects can manifest at various levels, from genetics to populations, and research into these effects is critical for gaining a better understanding of the environmental and evolutionary patterns of pesticidal resistance. Unfortunately, there are very limited studies about the residual toxicity of methomyl and lambda-cyhalothrin against PMB infesting cassava leaves, particularly in the Philippines, thus this study was conducted. The knowledge generated from this study is also important, as part of IPM strategy of the pest, particularly in determining the number of days when to release biocontrol agents, detecting which life stage of PMB most vulnerable to insecticide control, and identifying the time when cassava leaves are safe to eat as vegetables after being sprayed.

MATERIAL AND METHODS

Collection and mass rearing of papaya mealybug:

Egg masses of the PMBs were used to initiate the experiments and were brough to the Pest Laboratory of Visayas State University (VSU) and transferred to cassava (*Manihut esculenta*) plants (Lakan 1 variety) as food for mass production (Mani and Shivaraju, 2016). PMBs were allowed to hatch to start a biology for two generations (Mani and Shivaraju, 2016). Different life stages of laboratory reared PMBs were used in this experiment. The PMG egg mass and cassave leaf samples were all reared and grown inside a greenhouse/nursery in the Phiippine Rootcrops of Visayas State University.

Preparation of cassave plants:

Leaves of cassava plants (Lakan 1 variety) were obtained to feed PMBs throughout the experiment. plants are grown in a mixture of rice hull and soil in 1:1 ratio and were placed in ethylene bag. Nine cuttings of cassava plants, about 20 cm long, were planted into each bag (Abass *et al.,* 2014). The cuttings were allowed to grow outside of the pest laboratory of the Philippine Root Crops Research and Training Center (PhilRootCrops) for 2.5 months. To maintain a consistent number of cassava plants roughly of the same age which is necessary to supply enough amount of leaves for the whole duration of the experiment, systematic plantings were adopted (Abass *et al.,* 2014).

Preparation of insecticide solution and its insecticidal application:

The insecticide formulation tested for methomyl (Lannate®, Methomyl 90 WSP Insecticide, Dupont) contains 90% w/v of methomyl (S-methyl-N-[methylcarbamoyl)oxy]thioacetimidate) and 10% w/v other ingredients (USEPA, 1968). This formulation is a soluble powder (SP) insecticide used to control foliage and soil-borne insect pests on a variety of food and feed crops. In the experiment, the recommended rate that was used for methomyl is 20 g/16L of water (USEPA, 1968).

On the other hand, the insecticide formulated tested for γ-cyhalothrin (Karate®, Syngenta) contains 22.8% w/v of γ-cyhalothrin[1,2] and 77.2.% other ingredients (USEPA, 2020). This formulation is an emulsifiable concentrate (EC) insecticide used to control larvae of pests on crops such as cottons and cereals. In the experiment, the recommended rate that was used for γ-cyhalothrin is 15ml/16L of water (USEPA, 2020).

Contact Toxicity Assay and Residual Toxicity Assay:

Methomyl and γ-cyhalothrin insecticides were sprayed evenly onto the leaf using a Mecafer AG4 airbrush (Mecafer Co., Valence, France) using a total volume of rate 1mL-2mL per cassava plant to make sure all the leaves contain the insecticide. Spraying was done in late afternoon to minimize loss of toxicity due to photolysis (Tomlin, 2009). Then, the cassava plants were marked as follows:

(a) Treatment 1: Cassava plant 1- was sprayed daily with methomyl

(b) Treatment 2: Cassava plant 2- it was sprayed with methomyl once, and was performed at the beginning of the experiment (c) Treatment 3: Cassava plant 3- was sprayed daily with γ-cyhalothrin

(d) Treatment 4: Cassava plant 4-it was sprayed once, and was performed at the beginning of the experiment

(e) Control Group: Cassava plant 5- was sprayed daily with water

Preparation of Crude Ustiloxin Extracts:

According to Shan *et al*. (2013), the powdered sample was extracted from rice false smut spores (350 g) with deionized water (1L) at room temperature under ultrasound for 30 min. A rotary evaporator under vacuum at 60 °C was used to concentrate the water solution and get rid of excessive water. The net extract was stored at 4°C until needed..

Both contact toxicity assay and residual toxicity test were adapted from the pesticide manual of Tomlin (2009). Insecticide-sprayed and water-sprayed cassava leaf samples were taken right away after spraying within 2 days interval. To obtain the leaf discs, cassava leaves were harvested, washed twice with 1% NaClO solution and distilled water. The collected cassava leaf samples were cut into circular discs (diameter= 3cm) and placed in a petri dish lined with sponge and Whatman No.1 filter paper disk, to allow water saturation and minimize desiccation. Twenty (20) PMBs from each developmental stage reared in the laboratory were introduced into each treatment and replicated three times for each of the insecticide tested. The treatments were repeated and observed until such time as no more insect mortality was noted from previously sprayed leaves (**Fig. 1**). Dead insets were identified when no movements were observed after probing with a needed in the cervical region (Abass *et al.,* 2014).

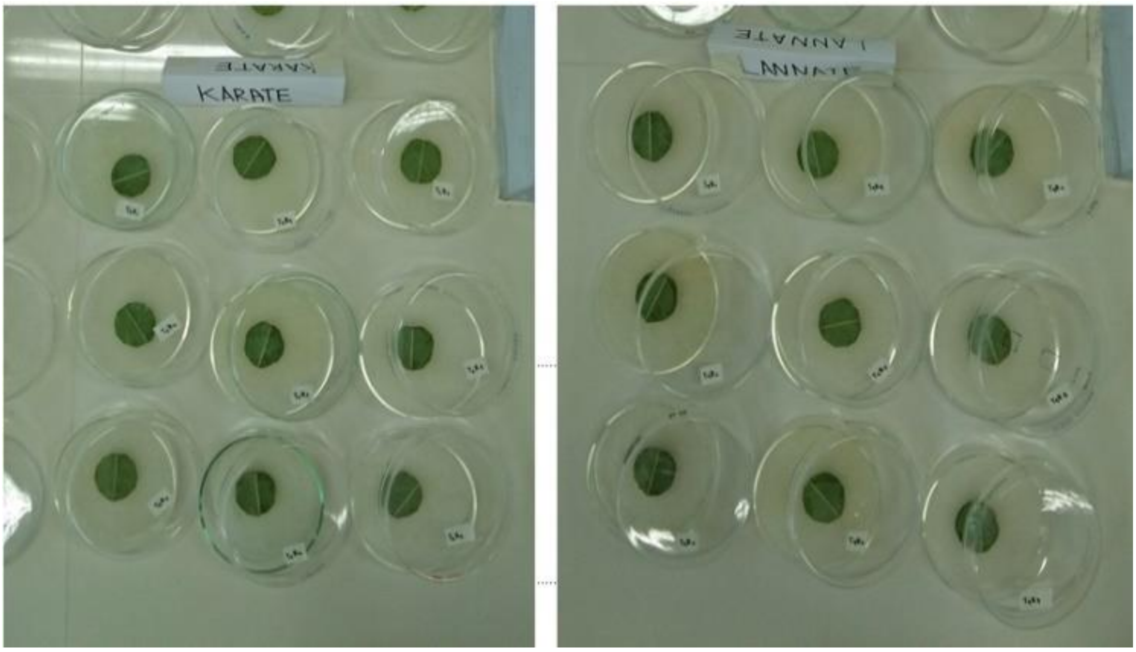

Fig. 1. Leaf-dip assay of methomyl and γ-cyhalothrin.

Statistical analysis:

All mortality data were corrected using Abbott's formula (Abbott, 1925). The results of the assay, in terms of the number of PMBs and its mortality, is presented as means ± standard deviations (mean ± SD). The normality was tested using Shapiro-Wilk test. For multiple comparisons, adult mortality levels after various exposure intervals were analyzed using mixed ANOVA (MANOVA) Fit Repeated Measures Procedures, with repeated measures as variable and treatment. Significant data by ANOVA were subjected to the Bonferroni test for mean separation. To determine significant differences among exposure intervals, ANOVA was employed for each treatment, PMBs, and storage interval (1st, 3rd, 5th, 7th, and 9th day). The lethal concentrations LC_{50} and LT_{50} and 95% confidence interval for each regression coefficient were calculated using probit analysis (Finney, 1971). Further, probit was graphed against $\log_{10}$ concentrations thus yielding a slope-intercept equation. From the equation, ($y=ax+b$), the slope (x) was then calculated. All data were analyzed using Minitab Version 21.1.0 at $p<0.05$.

RESULTS

The mean mortality rate in every developmental stage in cassava leaves (Lakan 1 variety) is shown in **Table 1**. Data showed a decreasing mortality rate in the three developmental stages of PMB with time. On the first and third day of the experiment, γ-cyhalothrin killed 100% of the neonates, 18 % on the fifth day 12% on the seventh day. For the pre-adults, it was 35%, 30%, 23% and 9%, respectively. In contrast, adults also showed a reduction in mortality which is slightly equivalent to pre-adults. For methomyl, the pre-adult and adult stages also showed a reduction in mortality mortality, from 48% on the first day to 8% on the seventh day compared to crawlers that recorded a 100% mortality on the first and third day while 8% on the seventh day. No mortality was observed on the 9th day**.** As also shown in Table 1, both γ-cyhalothrin and methomyl did not achieve 100% mortality of the pest in the pre- adult and adult stages.

Table 1. Means of mortality for each stage in γ-cyhalothrin and methomyl over time

Insecticide	Stages	Length of Treatment				
		1st day of treatment	3rd day of treatment	5th day of treatment	7th day of treatment	9th day of treatment
γ-cyhalothrin	Crawler	100 ± 0.00	100 ± 0.00	17.67±2.52	12±20	0±0.00
	Pre-adult	35 ± 10	29.67 ± 0.58	22.67±0.58	8.67±0.58	1.33±0.58
	Adult	35 ± 10	27.67 ± 3.21	21±2.65	8.33±0.58	1±10
Methomyl	Crawler	100 ± 00	100±00	40±00	8±00	0±00
	Pre-adult	47.67 ± 0.58	31.67±0.58	24.67±0.58	8.33±0.57	0±00
	Adult	43.33 ± 1.15	31.33±0.58	22.67±1.15	8.33±0.58	0±00

Table 2. Multiple interaction between subject factors mixed ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	p-value	Partial Eta Squared
Days	50461.289	4	12615.322	15500.055	.000	.999
days*insecticide	375.067	4	93.767	115.208	.000	.906
days*stage	19042.844	8	2380.356	2924.669	.000	.998
days*insecticide *stage	566.133	8	70.767	86.949	.000	.935
Error(days)	39.067	48	.814			

Table 3. Pairwise comparison between Methomyl and γ -cyhalothrin (Bonferroni Test)

Mean Difference	Std. Error	p value	95% Confidence Interval for Difference	
			Lower Bound	Upper Bound
-3.067*	.360	.000	-3.850	-2.283

Table 2 shows multiple interaction between subject factors mixed ANOVA test. It was used because there was a time component present, and two other factors (i.e., insecticide and developmental stages). Results in **Table 2** indicated that there was an interaction among the three factors (i.e., days*insecticide*stage) (F(8, 48)=86.949, p=0.000). This means that the residual toxicity of the insecticides varied across developmental stages, between insecticides and across days. Post hoc analysis with a Bonferroni test revealed that there was a difference in the residual toxicity between methomyl and γ-cyhalothrin (-3.067 [95% CI. -3.850 to -2.283], p=0.000) (**Table 3**).

In terms of the pairwise test for the insecticide, comparing the efficacy of methomyl and γ-cyhalothrin, it showed that there was a difference in the effect of the insecticides based on the mortality rate data (p=0.000). This difference is 3.067%, which showed that methomyl recorded 3.067% greater mortality compared with γ-cyhalothrin. The multiple comparison test used was Bonferroni, since this is a conservative test for detecting differences.

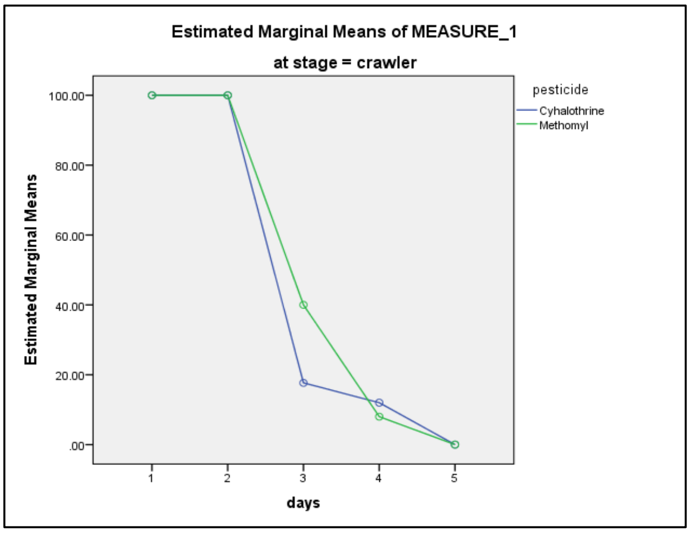

Fig. 2. Line graph for residual toxicity per insecticide per day for crawlers

The line graph showed that γ-cyhalothrin and methomyl were both effective against PMB crawlers (**Figure 2**). As shown in the graph, a 100% mortality was manifested during in Days 1 and 3 of the study.

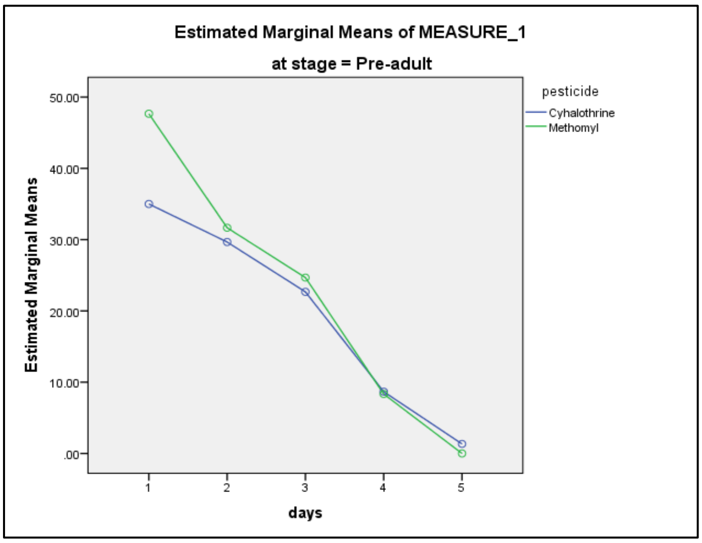

Fig. 3. Line graph for residual toxicity per insecticide per day for pre-adult

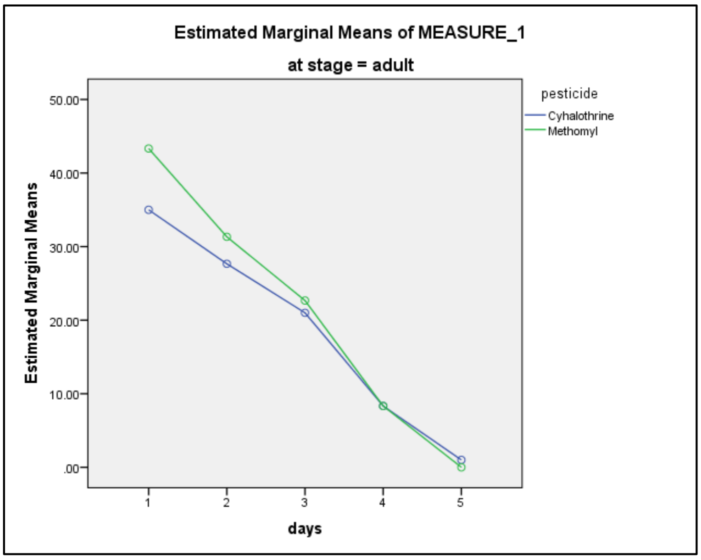

Fig. 4. Line graph for residual toxicity per insecticide per day for adult

The residual toxicity of the two insecticides against the three stages of PMB is summarized in **Table 4**. Probit regression summary results showed that LT_{50} values which determined the number of days the insecticide stayed on the cassava leaf. The estimated LT_{50} values of the succeeding timepoints were 5.065 days, 1.071 days, and 0.628 days, respectively for methomyl, while 4.715 days, -0.163 days, and -0.296 days for γ-cyhalothrin (**Table 4**). The crawlers being the most susceptible to the insecticide, took 5 days as the half-life of methomyl and 4.7 days for γ-cyhalothrin. LT_{50} indicated the number of days after spraying that caused 50% mortality of the population tested, and these values were expressed as $\log_{10}$.

Table 4. Probit regression summary of the Lethal Time (LT50) of the two effective insecticides against PMB

Pesticide	stage	Total	X^2	Regression equation	LC_{50}	Fiducial Limits	
			p=0.01	(slope)	Days	Lower Limit	Upper Limit
Methomyl	crawler	20	31.59**	3.736 - 0.792	5.065	4.760	5.359
	pre-adult	20	6.23	-0.031 - 0.190	1.071	-0.397	1.993
	adult	20	5.46	-0.056 - 0.190	0.628	-1.131	1.670
γ-cyhalothrin	crawler	20	8.88	4.226 - 0.834	4.714	4.124	5.245
	pre-adult	20	4.65	0.249 - 0.233	-0.163	-2.733	1.184
	adult	20	4.04	0.138 - 0.221	-0.296	-2.951	1.081

**significant

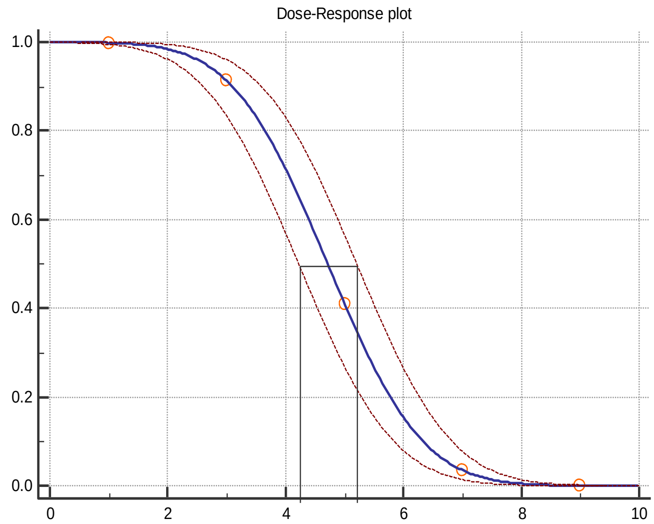

Fig. 5. Dose response plot for γ-cyhalothrin crawlers

The dose-response plot for the probit analysis of γ-cyhalothrin for crawlers showed to which days the residual toxicity decreased (**Fig. 5**). Dose-response of γ-cyhalothrin on cassava leaves, based on the result of the study, was 4.7 days (**Fig. 5).**

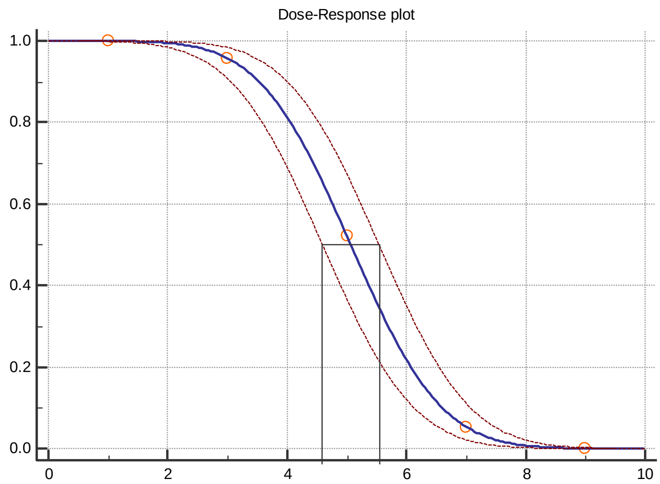

Fig. 6. Dose Response plot for methomyl crawlers

On the other hand, the dose-response plot for the probit analysis for methomyl showed an LT50 of 5 days (**Figure 6**). This means that the residual toxicity of methomyl is 5 days. Methomyl is a broad-spectrum carbamate insecticide, which can kill insects of Homoptera, Diptera, Coleoptera, highly toxic to adult and larval stages.

DISCUSSION

Papaya mealybug (*Paracoccos marginatus*) are oviparous insects (Franco *et al.,* 2009). Females usually lay 100-600 eggs in an ovisac covered with wax. The eggs hatch in 6-10 days into nymphs called crawlers (Walker *et al.,* 2010; Pramayudi *et al.,* 2022). The crawlers are the most active stage in the life cycle of PMB to cause infection, after hatching it will begin to crawl and disperse in search of food (Mwanauta *et al.,* 2022). The mobile crawlers can spread all over the plant or passively dispersed to neighboring plants by wind, water, ants and humans. Mealybugs are difficult to kill, they have defense systems like their ability to hide in the deep crevices and underside of the plant body making insecticides difficult to penetrate and waxy body covering produced by the epidermal glands transported to the body via ducts, pores and secretory setae. Effective PMB control is achieved when most of the population is in the crawler stage and the host plant does not provide effective shelter for them (Franco and Menzel, 2009). Control is achieved when most of the PMB population is in the dispersed crawler stage. After hatching from eggs, the crawler stage lack the waxy cover, therefore this is the stage most susceptible to the lethal effects of chemical insecticides (Walker *et al.,* 2006). The results of this study indicated that both insecticides, γ-cyhalothrin and methomyl, registered a 100% mortality of the pest during the first and third day of treatment. However, in the study of Karar *et al.* (2010), γ-cyhalothrin reported only 74.85% mortality on the crawlers of mango PMB after 24 hours of spray. The insect used in this study were laboratory reared and taken from the cassava field of the campus were spraying is prohibited a reason for the disparity of the result. Thereafter, as the crawler disperse and settle the soft portions of stem and leaves to start sucking the sap with its piercing sucking mouthparts, it will grow and transform into its next life stage (Mani and Shivaraju, 2016; Singh and Lal, 2007). Normally, once settled, they do not move except when disturbed. At this time the nymph will grow, secrete and embed themselves in waxy coating (Sakthivel *et al.,* 2012). This wax covering of the mealybug in the pre-adult and adult stages of PMB makes the pest hard to kill. The wax coating act as waterproof covering, hindering the penetration of chemical pesticide (Mwanauta *et al.,* 2021). This waxy coating over the body of PMB makes chemical control measures partially effective (Mani and Shivaraju, 2016).

Similarly, in the study of Karar *et al.* (2010), it is reported that γ-cyhalothrin killed only 63.43% pre-adults and 31.89% adults after 24 hours of spay. The waxy coating makes insecticide application difficult to kill the pest. Because of the presence of this mealy covering, Fatima *et al.* (2016) applied a combination of two insecticides for greater efficacy in the control mango mealybug (*Drosicha mangiferae*).

The sensitivity of PMB crawlers to the tested insecticides is due to the soft and thin covering of the pest and the penetration of the insecticide is thought to occur through the integument of the body wall and trachea (Gerolt, 1983; Scoy *et al.,* 2013; Amarasekare *et al.,* 2014). According According to the classification method of the Committee on Pesticide Resistance Action (IRAC), both methomyl and γ-cyhalothrin are insecticides aimed at the nervous and muscular system (Sparks and Nauen, 2015). Methomyl, a carbamate, belonging to main group 1 (acetylcholisnesterase inhibitor whereas lamda- cyhalothrin a pyrethroid, is a voltage gated channel modulator belonging to main Group 3 (Sparks and Nauen, 2015). Although both are relatively old insecticides, carbamates being introduced in the market in 1966, and pyrethrin in 1977, the estimated global sales of pyrethroid and carbamates peaked at 16% and 4%, respectively, indicating that these insecticides are still popular to many end users particularly the farmers (Sparks and Nauen, 2015). Pyrethroids are neuro-poisons acting on axons in the peripheral nervous and central nervous channels in mammals and insects (WHO, 2020). It usually slows down depolarization of the nerve membrane which reduces the amplitude of the action potential leading to a loss of electrical excitability. Once the insect becomes intoxicated, it gets paralyzed and eventually dies (Shaurub and El-Aziz, 2015; EL-Saeid *et al.,* 2022). On the other hand, methomyl is a carbamate cholinesterase inhibitor depressing cholinesterase activity in the blood and brain of mammals and insects (Desaeger *et al.,* 2011; Bellote *et al.,* 2012). Methomyl's mode of action is inhibitory to acetylcholine cholinesterase from binding to the active site of the enzyme. Therefore, the neurotransmitter acetylcholine is not deactivated and this lead to a continuous and persistent stimulation of the postsynaptic membrane in neurons giving rise to immediate hyperactivity, paralysis and eventual death of the insects. Methomyl is a fast acting insecticide (Wyckhuys *et al.,* 2019). Both insecticides were highly toxic to the crawlers. PMB crawlers are most susceptible to insecticide application during the first instar nymphal populations where they are most susceptible to chemical treatment. Comparatively, methomyl and γ-cyhalothrin were not able to control the pre-adults and the adult stages completely, as well as the white mealy secretion, waxy cover, and fibers provide protection to the pest. This makes insecticide spray less desirable and ineffective.

γ-cyhalothrin is a man-made chemical introduced to the market in 1977 (USEPA, 2020). It is a contact and stomach-poisoning insecticides with repelling properties. It is mainly used in agricultural pesticide on a wide variety of crops because of its low application rates and rapid degradation in the environment and residues in food are generally low (WHO, 2020). It is biodegradable and the safest pesticides used in agriculture and farming because it is less toxic and safe for protection of vegetables that can be eaten raw (Lutap and Atis, 2013). In this study, the LT_{50} of γ-cyhalothrin on cassava leaves is 4.7 days. This result is at par with WHO (2020) reporting that the half-life of γ-cyhalothrin in plants is up to 4 days. In the study of Shalay (2017), γ-cyhalothrin likewise stayed 6 days on fruits; 3.45 days on the leaves of pepper; and, 4.8 days in rice during the milking stage of the crop at 36 days after transplantation (Heong *et al.,* 1994). This is also similar in okra, where the γ-cyhalothrin half –life is 2.86-2.92 days (Jhala *et al.,* 2010).

When methomyl is applied to the plant, its residues are short- lived and limited foliar translocation (Scoy *et al.,* 2013). The findings of this study showed that the half- life of methomyl is 5 days, which is consistent with the pesticide information profile which is 3- 5 days (USEPA, 1968) In a similar study, when the insecticide was sprayed on cabbage, less than 3% of the insecticide remained after 7 days while in nicotine leaves methomyl stayed for 3-7 days (Walker *et al.,* 2006). Carbamate is a restricted use insecticide because of its high water solubility and high toxicity to non-target organisms, including fishes and invertebrates. Proper timing during spray application, avoidance of multiple spraying in short duration and observing insecticide rotation is an effective strategy in controlling PMB, thus preserving ecological balance and environmental safety of the agroecosystem.

CONCLUSION

Both methomyl and γ-cyhalothrin are maximally effective in controlling PMB crawlers but minimally effective to the pre-adults and the adult stage. Insecticides in general are part of pest control and they have to be used in the right time, right kind and right amount. Proper timing of application needs to be observed most especially at the time when the PMB eggs are hatching. In this way, environmental pollution is prevented and the natural enemies are preserved. As to residual toxicity, methomyl dissipates from the surface of cassava leaves 7 days after application meaning farmers has to wait 7 days for their next spray application. Relatively, the dissipation time of the γ-cyhalothrin is 4.7 days. Insecticides are part of integrated pest management in the control of pest, for they are effective and reliable in killing pest. However, care must be taken in their spray application because methomyl and γ-cyhalothrin are highly toxic to natural enemies, birds, fishes and aquatic invertebrates. This study is conducted only in the laboratory setting so it is recommended that a field experiment be done for evaluation purposes. I tis recommended that: (1) studies on the residual toxicity of Cartap and Cypermethrin be conducted as these two pesticides can be used as rotating partners to delay insect cross- resistance in PMB; (2) residual toxicity of methomyl and γ-cyhalothrin need to be evaluated under field conditions; and (3) additional studies focused on the residual toxicity of methomyl and γ-cyhalothrin should be performed to determine safe and effective insecticides to economically-important food crops and vegetables.

Funding: Not applicable.
Conflict of Interest: The authors declare no conflict of interest.

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