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Sustainable Management for Spiralling Whitefly, *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae) Infesting Guava and Its Effects on the Natural Enemies' Complex

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Abstract

The spiralling whitefly, Aleurodicus dispersus (Hemiptera: Aleyrodidae), is one of the most notorious insect pests among tropical fruits and vegetables. A common pest management technique is the application of chemical insecticides. However, this has led to environmental degradation, natural enemy reduction, development of pesticide resistance and increased cost of production. This study, therefore, evaluated the efficacy of a sustainable and eco-friendly management strategy against the spiralling whitefly infesting guava (Psidium guajava L). The experiment was carried out with seven treatments replicated five times following the randomized complete block design. The treatments were negative control (T1), 0.8% soybean oil (T2), 1.6% liquid dishwashing (T3), 1.6% neem oil (T4), 0.4% soybean oil + 0.8% liquid dishwashing (T5), 0.8% neem oil + 0.8% liquid dishwashing (T6) and chemical control (Thiamethoxam 25 WG at 2g/L^{-1}) (T7). Results showed that 1.6% liquid dishwashing was superior among treatments against the 1st, 2nd and 3rd nymphal instars with an average mortality of 84.28, 85.22 and 81.81%, respectively. Application of 0.8% soybean oil showed the highest efficacy against the eggs, 4th instar and adult population with an average mortality of 75.50, 81.36 and 93.50%, respectively. Application of these treatments showed no adverse effects on the natural enemies' complex associated with guava. Integration of other eco-friendly pest management strategies against the invasive spiralling whitefly is recommended for future research.

***Keywords**:* guava, natural enemies, pest management, spiralling whitefly

1. Introduction

Guava (*Psidium guajava* L.) of the family Myrtaceae is one of the most important commercially grown fruit crops in most tropical and subtropical countries worldwide (Singh, 2011; Gill, 2016; Khan, 2017). Guava fruit has a lot of essential vitamins, minerals, dietary oxidants and fiber (Lubis *et al*., 2017). Here in the Philippines, guava fruit is locally known as 'bayabas.' Its production from 2015 to 2017 was estimated to be at 10.8 thousand metric tons (Altendorf, 2018). This shared about 4.1% of the total fruit crop production in the country (Philippine Statistics Authority, 2020).

However, guava production has recently been threatened by various biotic stresses including the spiralling whiteflies, *Aleurodicus dispersus* Russell, under the family Aleyrodidae of the order Hemiptera (Khushk *et al*., 2009; Gundappa *et al*., 2018; Sampiano and Aceres, 2021). This pest negatively affects the crop's physiology and economy (Puritch *et al*., 1982; Rashid *et al*., 2003). In Taiwan and India, there were yield decreases of up to 80% for guava fruits (Wen *et al*., 1995) and up to 53% for cassava (Geetha, 2000). A typical management approach against pests is the use of synthetic insecticides (Roy *et al*., 2014; Khan, 2017). However, intensive use of these chemicals has a negative impact on the environment (Sanchez-Bayo, 2012), human health (Kumar *et al*., 2012) and the activity and abundance of the natural enemies (Abdel-Raheem, 2021); these chemicals can also trigger insecticide resistance to the pest (Chand *et al*., 2019).

Eco-friendly management strategies against insect pests have been explored in the past decades. These include the use of plant-based oils and insecticidal soaps (Singh *et al*., 2012). For instance, soybean oil was reported as highly effective against corn weevil (*Sitophilus zeamais*) (Koona and Njoya, 2004). Neem oil extracted from the neem tree was used to control flower thrips (Thysanopetra) infesting mango (Aliakbarpour *et al*., 2011). Meanwhile, common household detergent showed higher toxicity rate against the destructive fall armyworm (*Spodoptera frujiperda*) (Aniwanou *et al*., 2020).

Although eco-friendly management strategies against spiralling whitefly have been explored in other countries (Iram *et al*., 2014; Alim *et al*., 2017; Khan, 2018), no sufficient efforts have been made in the Philippines (Sampiano and Aceres, 2021). The present study, therefore, evaluated the efficacy of soybean oil, neem oil and liquid dishwashing against the spiralling whitefly attacking guava fruit. This work also determined the adverse effects of the proposed management approach toward the natural enemy complex associated with guava.

2. Methodology

2.1 Location and Duration

The present work was conducted at the Guava Research and Production Area (7.2734° N and 125.8532° E) of the University of Southeastern Philippines (USeP), Tagum-Mabini Campus, Mabini Unit, Davao de Oro, Philippines. The experimental field was planted with guava trees (*Psidium guajava* L.) with a spacing of 5 x 5 m and without overlapping canopies. The study was conducted in May 2022.

2.2 Cultural Management

Appropriate cultural management for guava production was implemented throughout the field study based on the production guide of the Bureau of Plant Industry (2016). Weeding was done as soon as the weeds appeared in the study area using grass-cutting tools. Diseased branches, sprouts and unproductive parts of the trees were removed using pruning tools before the onset of the experiment. Finally, organic fertilizer (vermicompost) was applied through side dress application.

2.3 Materials

This study utilized commercial formulations of neem oil (NB®, Seeds Store, Philippines), liquid dishwashing (Joy®, Procter and Gamble Philippines, Inc., Philippines), soybean oil (Simply®, Wilmar Trading Pte Ltd, Singapore) and the chemical insecticide, Thiamethoxam, (Actara®, Syngenta, Philippines). The materials were procured through an online platform. When the treatment materials were delivered, they were automatically stored at the entomology laboratory (an air-conditioned room [18 ± 2 °C]) of the USeP Tagum-Mabini Campus until they were used in the experiment.

2.4 Experimental Design and Treatments

The field trial was laid out in a randomized complete block design (RCBD) having seven treatments replicated five times with one guava tree per treatment replicate. A preliminary trial was conducted to determine the phytotoxic effects of treatments on guava plants. The treatments are presented in Table 1. All treatments at the designated concentrations were applied after the field was confirmed for a heavy whitefly infestation. Treatment application (approximately 2 L per tree) was done by spray method using a batteryoperated knapsack sprayer with pressure regulator (KC-16, Kawasaki Heavy Industries Ltd, Japan) until the point of run-off and was done from 6:00 AM to 8:00 AM. Spraying was administered only once in 15 days for the present study because there was no infestation thereafter that necessitated another round of application.

Table 1. The experimental treatments of the study

Treatment code	Description
T1	Untreated control (no application of any treatment)
T2	0.8% soybean oil
T3	1.6% liquid dishwashing
T4	1.6% neem oil
T5	0.4% soybean oil + 0.8% liquid dishwashing
T6	0.8% neem oil + 0.8% liquid dishwashing
T7	Chemical control (Thiamethoxam 25 WG at 2 g/L^{-1})

2.5 Data Collection Procedure

Pre-treatment data on the population of whiteflies with all stages were collected one day before the administration of treatments. After the spray, three infested leaves of the guava tree were randomly collected from different strata (upper, middle and lower) of the plant to record the mortality of spiralling whitefly. The collected leaves were held carefully inside the transparent zip bag and then secured to prevent the escape of the whitefly (Khan, 2017). The undisturbed leaf samples were brought to the entomology laboratory for further examination. The number of eggs, 1st, 2nd, 3rd and 4th instars, and adult whiteflies per leaf sample was counted manually under an optical stereo microscope (NexiusZoom NZ.1902-P, Euromex®, United States) with 20x magnification (Sparks *et al.*, 2020). The nymphal instars of the pest were morphologically distinguished according to the description of Boopathi (2017). Post-data collection and sampling were done at 3, 7, 10 and 15 days after the treatment application. Newly infested leaves were randomly collected from the field during every observation. Data on percentage mortality in the treatments are corrected for natural mortality recorded on the control using Henderson-Tilton’s formula (Henderson and Tilton, 1955) presented as Equation 1.

$$Corrected\ mortality = 1 - \frac{(Ca) \times (Tb)}{(Cb) \times (Ta)} \times 100 \qquad (1)$$

where *Cb* is the number of insects in the untreated control before application; *Ca* is the number of insects in the untreated control after application; *Tb* is the number of insects in the treatment before application; and *Ta* is the number of insects in the treatment after application.

The effects of the treatments on the natural enemy populations, on the other hand, were established by counting the natural enemies a day before the treatment administration followed by 3, 7, 10 and 15 days after treatment. Population densities of predators and pollinators were estimated through in situ visual counting at the upper, middle and lower canopy, and in all directions from north, south, east and west portions of the guava plant (Boopathi *et al*., 2017). Meanwhile, the *Encarsia guadeloupe*, the known whitefly parasitoid, was estimated by collecting three randomly selected leaves infested with 3rd to 4th nymphal instar of spiralling whitefly and held in the entomology laboratory until the emergence of parasitoids (Boopathi *et al*., 2017).

2.6 Data Analysis

The data collected from the experiment were subjected to analysis of variance (ANOVA) following the RCBD. Square root transformation ($\sqrt{x}+0.5$) was performed before variance analysis to stabilize errors and improve normality (Oliveira *et al*., 2018). Treatment means were then compared using Tukey's honestly significant difference test (Abdi and Williams, 2010). All statistical tests were considered significant at p < 0.05 and performed using the Statistical Tool for Agricultural Research version 2.0.1 software (International Rice Research Institute, 2013).

3. Results and Discussion

3.1 Mortality of A. disperses

3.1.1 Bio-efficacy of the Treatments against the Eggs

The pre-treatment number of spiralling whitefly eggs ranged from 19.60 to 26.40 as shown in Table 2. No significant differences were found in the pre-treatment means indicating a homogenous number of spiralling whitefly eggs in the field. After applying the treatments, all of them caused a significant reduction of the whitefly eggs over the untreated control. Application of 0.8% soybean oil showed 53.71 and 97.82% at 3 and 10 days after spray (DAS), respectively, and was superior among treatments. Meanwhile, 0.4% soybean oil + 0.8% liquid dishwashing showed 82.38% mortality over the untreated control at 7 DAS. At 15 DAS, 1.6% liquid dishwashing showed the highest efficacy recording 92.88% mortality, which was at par with the chemical control. The overall highest mean mortality of eggs over the untreated control was 75.50% and recorded by 0.8% soybean oil.

Table 2. Percent mortality of *A. dispersus* eggs in guava as affected by the treatments

Treatments	PTC^{ns}	Corrected (%) mortality of eggs/3 leaf samples				
		3 DAS	7 DAS	10 DAS	15 DAS	Mean mortality
Untreated control	22.40	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Soybean oil (0.8%)	23.00	53.71^{a}	63.27^{a}	97.82^{a}	87.18^{a}	75.50^{a}
Liquid dishwashing (1.6%)	26.40	31.63a^{b}	78.56^{a}	89.99^{a}	92.88^{a}	73.27^{a}
Neem oil (1.6%)	21.40	49.32^{a}	46.70^{a}	82.70^{a}	81.33^{a}	65.01^{a}
Soybean oil (0.4%) + liquid dishwashing (0.8%)	19.60	35.05^{ab}	82.38^{a}	86.11^{a}	90.38^{a}	73.48^{a}
Neem oil (0.8%) + liquid dishwashing (0.8%)	24.60	36.13^{ab}	48.34^{a}	85.45^{a}	87.33^{a}	64.31^{a}
Chemical control (Thiamethoxam 25 WG at 2 g/L^{-1})	21.00	62.44^{a}	95.82^{a}	95.71^{a}	100.00^{a}	88.49^{a}
F-value	0.13	3.60	11.02	122.92	19.00	49.3
SEM	2.27	5.47	6.32	5.74	6.01	9.65
P-value	0.99	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Values are the mean of the five replicates. Means followed by similar superscripts did not differ statistically after Tukey's test; DAS – days after spray, PTC – pre-treatment count, SEM – standard error of the mean.

3.1.2 Bio-efficacy of the Treatments against the 1st Nymphal Instar

The pre-treatment number of spiralling whitefly 1st nymphal instar ranged from 15.4 to 32.2 as presented in Table 3. There were no significant differences among the pre-treatment means, indicating the 1st nymphal instar was uniformly distributed in the field. Post-treatment data showed that all of the treatments caused a significant reduction of the 1st nymphal instar over the untreated control. Application of 0.8% soybean oil recorded 53.88% mortality at 3 DAS. Meanwhile, 0.4% soybean oil + 0.8% liquid dishwashing showed 94.75% efficacy at 7 DAS. On the other hand, 1.6% liquid dishwashing showed 97.02% and 95.78% efficacy against the 1st nymphal instar at 10 and 15 DAS, respectively, and was found comparable with the chemical control. Application of 1.6% liquid dishwashing registered the overall highest mean mortality of 84.28% over the untreated control.

Table 3. Percent mortality of *A. dispersus* 1st nymphal instar in guava as affected by the treatments

Treatments	PTC^{ns}	Corrected (%) mortality of 1st nymphal instar/3 leaf samples				
		3 DAS	7 DAS	10 DAS	15 DAS	Mean mortality
Untreated control	15.40	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}
Soybean oil (0.8%)	18.80	53.88^{a}	88.60^{a}	96.24^{a}	93.90^{a}	83.15^{a}
Liquid dishwashing (1.6%)	32.20	53.14^{a}	91.17^{a}	97.02^{a}	95.78^{a}	84.28^{a}
Neem oil (1.6%)	20.60	40.68^{ab}	64.76^{a}	81.37^{a}	95.61^{a}	70.61^{a}
Soybean oil (0.4%) + liquid dishwashing (0.8%)	21.40	36.92^{ab}	94.75^{a}	93.34^{a}	92.37^{a}	79.35^{a}
Neem oil (0.8%) + liquid dishwashing (0.8%)	19.60	27.71^{ab}	62.89^{a}	87.10^{a}	83.63^{a}	65.33^{a}
Chemical control (Thiamethoxam 25 WG at 2 g/L^{-1})	27.40	65.97^{a}	94.54^{a}	99.30^{a}	100.00^{a}	89.95^{a}
F-value	1.06	4.11	32.10	47.40	114.64	81.83
SEM	1.97	5.47	6.08	6.25	5.96	7.87
P-value	0.40	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Values are the mean of the five replicates. Means followed by similar superscripts did not differ statistically after Tukey's test; DAS – days after spray, PTC – pre-treatment count, SEM – standard error of the mean.

3.1.3 Bio-efficacy of the Treatments against the 2nd Nymphal Instar

Table 4 shows the number of spiralling whitefly 2nd nymphal instar before the treatment application ranging from 13.8 to 34.6. This was found to be homogeneously distributed in the field as indicated by the variance analysis. At 3 to 7 DAS, the application of 1.6% liquid dishwashing significantly recorded the maximum mortality of 51.14 and 96.42% and was found comparable with the chemical control. At 10 DAS, the application of 1.6% neem oil significantly registered the highest mortality of 99.12%, which was similar to the chemical control. At 15 DAS, 98.70% mortality of the 2nd nymphal instar was significantly recorded by 0.4% soybean oil + 0.8% liquid dishwashing. The overall highest mean mortality over the untreated control was 85.22% and was registered by the application of 1.6% liquid dishwashing.

3.1.4 Bio-efficacy of the Treatments against the 3rd Nymphal Instar

Table 5 presents the pre-treatment data of spiralling whitefly 3rd nymphal instar that ranged from 15.2 to 32.4. This was found to be uniformly distributed in the field as revealed by the variance analysis. At 3 DAS, the application of 1.6% liquid dishwashing effectively recorded 52.47% mortality over the untreated control. At 7 DAS, 0.8% soybean oil registered 93.57%

mortality and was found to be similar to the chemical control. Meanwhile, the application of 0.8% neem oil + 0.8% liquid dishwashing got the highest mortality of 98.21% at 10 DAS, which was higher than the chemical control. At 15 DAS, 0.4% soybean oil + 0.8% liquid dishwashing obtained the highest mortality of 98.09% and was comparable with the chemical control. Application of 1.6% liquid dishwashing yielded the overall highest mean mortality of 81.81% over the untreated control.

Table 4. Percent mortality *of A. dispersus* 2nd nymphal instar in guava as affected by the treatments

Treatments	PTC^{ns}	Corrected (%) mortality of 2nd nymphal instar/3 leaf samples				
		3 DAS	7 DAS	10 DAS	15 DAS	Mean mortality
Untreated control	13.80	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{b}	0.00^{c}
Soybean oil (0.8%)	19.80	32.65^{a}	72.88^{a}	94.29^{a}	96.85^{a}	52.92^{b}
Liquid dishwashing (1.6%)	34.60	51.14^{a}	96.42^{a}	97.40^{a}	96.68^{a}	85.22^{ab}
Neem oil (1.6%)	22.20	40.93^{a}	74.80^{a}	99.12^{a}	94.21^{a}	77.27^{b}
Soybean oil (0.4%) + liquid dishwashing (0.8%)	26.20	44.72^{a}	92.39^{a}	97.89^{a}	98.70^{a}	83.43^{ab}
Neem oil (0.8%) + liquid dishwashing (0.8%)	25.60	48.38^{a}	76.51^{a}	97.83^{a}	92.24^{a}	78.74^{b}
Chemical control (Thiamethoxam 25 WG at 2 g/L^{-1})	32.60	84.08^{a}	98.86^{a}	98.73^{a}	99.35^{a}	95.26^{a}
F-value	2.42	8.03	78.57	802.04	617.6	286.00
SEM	2.39	5.48	5.77	6.07	5.86	5.21
P-value	0.056	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Values are the mean of the five replicates. Means followed by similar superscripts did not differ statistically after Tukey's test; DAS – days after spray, PTC – pre-treatment count, SEM – standard error of the mean.

3.1.5 Bio-efficacy of the Treatments against the 4th Nymphal Instar

The pre-treatment number of spiralling whitefly 4th nymphal instar ranged from 13.8 to 43.2 as presented in Table 6. This was uniformly distributed across treatments as indicated by the variance analysis. At 3 DAS, 50% mortality was significantly recorded by 0.80% soybean oil which was found to be statistically at par with the chemical control. At 7 and 10 DAS, 87.09 and 96.34% mortality, respectively, over the untreated control was significantly recorded by 0.4% soybean oil + 0.8% liquid dishwashing. At 15 DAS, the highest mortality of 96.81% over the untreated control was obtained by 0.8% soybean oil and was found to be statistically similar to the chemical control. The overall highest mean mortality of the 4th nymphal instar was 81.36%, and this was significantly recorded by 0.8% soybean oil.

Table 5. Percent mortality of *A. dispersus* 3rd nymphal instar in guava as affected by the treatments

Treatments	PTC[ns]	Corrected (%) mortality of 3rd nymphal instar/3 leaf samples				
		3 DAS	7 DAS	10 DAS	15 DAS	Mean mortality
Untreated control	21.60	0.00[c]	0.00[c]	0.00[b]	0.00[b]	0.00[d]
Soybean oil (0.8%)	15.20	48.23[ab]	93.57[a]	97.93[a]	81.04[a]	80.19[abc]
Liquid dishwashing (1.6%)	26.20	52.47[a]	91.20[a]	92.58[a]	90.98[a]	81.81[ab]
Neem oil (1.6%)	21.60	42.10[ab]	75.27[ab]	95.04[a]	94.63[a]	76.76[bc]
Soybean oil (0.4%) + liquid dishwashing (0.8%)	17.20	9.38[bc]	89.62[a]	94.26[a]	98.09[a]	72.84[bc]
Neem oil (0.8%) + liquid dishwashing (0.8%)	17.80	26.14[abc]	63.35[b]	98.21[a]	80.05[a]	66.94[c]
Chemical control (thiamethoxam 25 WG at 2 g/L^{-1})	32.40	71.43[a]	96.61[a]	95.71[a]	100.00[a]	90.94[a]
F-value	1.28	7.48	103.19	699.1	27.23	330.51
SEM	2.02	5.32	5.73	5.82	6.46	4.99
P-value	0.3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Values are the mean of the five replicates. Means followed by similar superscripts did not differ statistically after Tukey's test; DAS – days after spray, PTC – pre-treatment count, SEM – standard error of the mean.

Table 6. Percent mortality of *A. dispersus* 4th nymphal instar in guava as affected by the treatments

Treatments	PTC[ns]	Corrected (%) mortality of 4th nymphal instar/3 leaf samples				
		3 DAS	7 DAS	10 DAS	15 DAS	Mean mortality
Untreated control	15.20	0.00[b]	0.00[c]	0.00[b]	0.00[b]	0.00[d]
Soybean oil (0.8%)	17.20	50.00[a]	83.40[ab]	95.11[a]	96.81[a]	81.36[abc]
Liquid dishwashing (1.6%)	24.40	32.01[a]	81.11[ab]	92.54[a]	80.90[a]	71.39[abc]
Neem oil (1.6%)	16.00	27.33[ab]	52.59[b]	94.85[a]	80.91[a]	63.92[c]
Soybean oil (0.4%) + liquid dishwashing (0.8%)	28.00	38.08[a]	87.09[a]	96.34[a]	95.59[a]	79.28[ab]
Neem oil (0.8%) + liquid dishwashing (0.8%)	13.80	27.40[ab]	74.97[ab]	94.76[a]	81.46[a]	69.65[bc]
Chemical control (Thiamethoxam 25 WG at 2 g/L^{-1})	43.20	80.48[a]	98.04[a]	99.10[a]	99.90a	94.38[a]
F-value	1.60	7.25	41.85	781.39	20.89	175.66
SEM	3.46	5.33	5.92	5.79	6.38	5.11
P-value	0.189	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Values are the mean of the five replicates. Means followed by similar superscripts did not differ statistically after Tukey's test; DAS – days after spray, PTC – pre-treatment count, SEM – standard error of the mean.

3.1.6 Bio-efficacy of the Treatments against the Adult

The pre-treatment number of spiralling whitefly adults ranged from 16.20 to 25.60 (Table 7). It was found to be uniformly distributed across treatments as revealed by the variance analysis. Significant differences among treatments were obtained at 3 DAS, wherein 0.8% soybean oil recorded the highest efficacy with 87.65% mortality over the untreated control. At 7 DAS, 1.60% liquid dishwashing significantly registered the highest mortality of 92.04% over the untreated control. At 10 DAS, the highest efficacy over the untreated control was recorded by 0.8% soybean oil registering 100% mortality. At 15 DAS, on the other hand, 0.8% neem oil + 0.8% liquid dishwashing significantly registered 98.21% mortality over the untreated control and was the highest among all treatments. Overall, the application of 0.8% soybean oil recorded the highest mean mortality of 93.50% over the untreated control.

Table 7. Percent mortality of *A. dispersus* adult in guava as affected by the treatments

Treatments	PTC^{ns}	Corrected (%) mortality of adult/3 leaf samples				
		3 DAS	7 DAS	10 DAS	15 DAS	Mean mortality
Untreated control	25.60	0.00^{b}	0.00^{c}	0.00^{c}	0.00^{b}	0.00^{c}
Soybean oil (0.8%)	21.40	87.65^{a}	92.04^{a}	100.00^{a}	94.30^{a}	93.50^{a}
Liquid dishwashing (1.6%)	20.20	75.51^{a}	95.05^{a}	94.69^{ab}	96.81^{a}	90.58^{a}
Neem oil (1.6%)	17.00	62.88^{a}	62.19^{b}	83.44^{b}	81.73^{a}	72.56^{b}
Soybean oil (0.4%) + liquid dishwashing (0.8%)	19.80	71.96^{a}	87.33^{ab}	93.71^{ab}	93.06^{a}	86.52^{a}
Neem oil (0.8%) + liquid dishwashing (0.8%)	24.80	70.97^{a}	81.21^{ab}	96.03^{ab}	98.21^{a}	86.61^{a}
Chemical control (Thiamethoxam 25 WG at 2 g/L^{-1})	16.20	72.43^{a}	94.09^{a}	97.25^{a}	100.00^{a}	90.94^{a}
F-value	0.82	31.92	71.58	497.55	128.25	402.36
SEM	1.48	5.42	5.88	5.80	5.98	5.41
P-value	0.56	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Values are the mean of the five replicates. Means followed by similar superscripts did not differ statistically after Tukey's test; DAS – days after spray, PTC – pre-treatment count, SEM – standard error of the mean.

The application of different eco-friendly insecticides was effective in managing the population of the spiralling whitefly infesting guava under field conditions. This study revealed that the application of 0.8% soybean oil caused 52.92 to 93.50% mean mortality against all stages of the pest. It indicated that the application of soybean oil is an effective and sustainable insecticide against the spiralling whitefly infesting guava.

Iram *et al*. (2014) found that soybean oil is effective against the cotton whitefly (*Bemisia tabaci*) infesting the sesame crop (*Sesamum indicum).* In comparison, Fenigstein *et al*. (2001) revealed that soybean oil was effective against the 1st to 3rd instar of sweet-potato whitefly (*B. tabaci*). Generally, plant-based oils' mode of action is more physical than chemical toxicity (Bogran *et al*., 2006). Soybean oil is composed primarily of fatty acids such as oleic, stearic, linoleic, palmitic and linolenic acids (Clemente and Cahoon, 2009). These fatty acids hinder oxygen flow leading to insect death (Fogang *et al*., 2012). Additionally, these fatty acids act as metabolic poisons disrupting insects' normal metabolic processes leading to death (Cranshaw and Baxendale, 2013).

The application of liquid dishwashing was also promising against the spiralling whitefly. Efficacy of liquid dishwashing was 73.27, 71.39 to 85.22 and 90.58% for eggs, nymphs and adults, respectively. Interestingly, the efficacy reached up to more than 80% when combined with soybean or neem oil. This result implied that the utilization of liquid dishwashing was still an effective treatment against the spiralling whitefly in guava.

Liquid dishwashing is a form of detergent that is typically used as household cleaner (Dai *et al*., 2019). Several studies have shown the effectiveness of detergents against several whitefly populations ranging from 66.75 to 100% (Liu and Stansly, 2000; Arias *et al*., 2006; Boopathi *et al*., 2014; Khan, 2018). However, the detergents' mode of action is still unclear until today, probably because of the advent of synthetic chemical insecticides (Curkovic, 2016). Despite this, detergents were previously known to act in multiple sites rather than specific target sites (Curkovic, 2007). Accordingly, it destroys the hydrocarbons in the insects' integument resulting in desiccation and death (Curkovic *et al*., 1993). Meanwhile, typical detergent contains surfactant that causes insects to dislodge away from the crop (Curkovic and Araya, 2004). Lastly, the surfactant properties of detergents allow the spray solution to enter into the tracheal system disrupting normal oxygen diffusion that leads to insect death (Szumlas, 2002).

The application of neem oil also showed satisfying biological activity against various stages of the spiralling whitefly. Application of 1.6% of neem oil showed 65.01, 63.92 to 77.28 and 72.56% efficacy against the eggs, nymphs and adults of spiralling whitefly, respectively. This result indicated that neem oil was still an effective management strategy to combat the field infestation of spiralling whitefly.

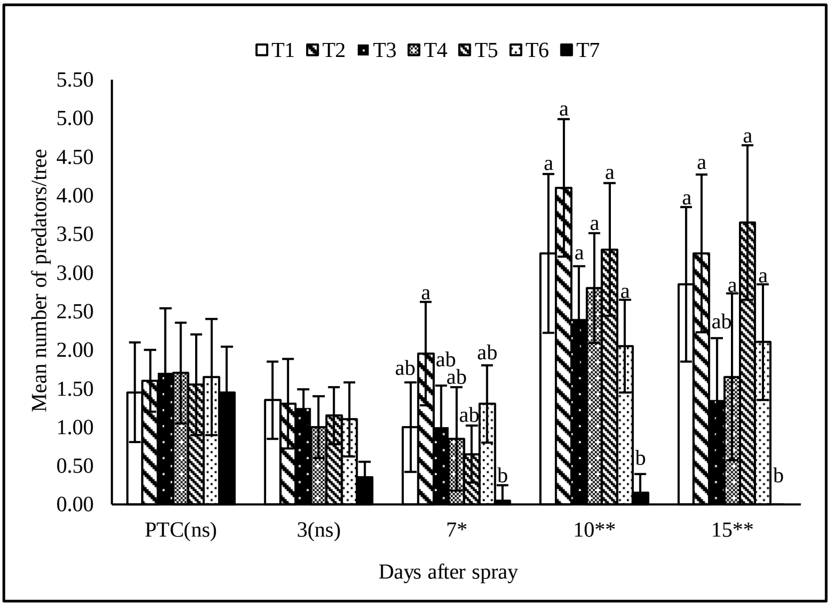
Previous reports showed that application of neem oil reduced the nymphal population of spiralling whitefly up to 91.7% in guava (Dubey and Sundararaj, 2004). Ur-Rehman *et al*. (2015) found that applying neem oil reduced the silver leaf whitefly's (*B. tabaci*) population by up to 70.77% in okra (*Abelmoschus esculentus*). Neem oil serves as an insect antifeedant because of azadirachtin, which affects the normal digestive process of insects (Adhikari *et al*., 2020). It also makes the insects incapable of reproduction (Berxolli and Shahini, 2017). Azadirachtin also inhibits the growth of insects by disrupting the function of ecdysone leading to the nonoccurrence of molting (Morgan, 2009).

The efficacy of soybean oil, liquid dishwashing and neem oil unexpectedly decreased at 15 DAS. This might be due to the low residual activity of the treatments (Miresmailli and Isman, 2014). These compounds are also prone to rapid photodegradation (Curkovic, 2016). They do not retain on the leaves for a longer period, thereby decreasing their efficacy against the spiralling whitefly. Meanwhile, these treatments were considered contact insecticides; thus, the population of spiralling whitefly that was not covered during the actual spray would have probably survived and recovered in the later days after the treatment application.

3.2 Population Changes of Natural Enemies as affected by the Treatments

3.2.1 Effects of the Treatments on Predators

Predators are a group of arthropods that consume live insects as their food to survive. In a natural ecosystem, they are considered an excellent regulatory force to control the population of several insect pest species. In this study, the observed predators in guava were ladybird beetles, *Chilocorus* spp. (Coccinellidae), hoverfly larvae (Syrphidae), predatory wasps, *Vespula* spp. (Vespidae) and spiders (Araneae). The average number of predators noted per guava tree through in situ samplings is presented in Figure 1. No significant differences were observed in the number of predators at pre-treatment and 3 DAS. However, there was an apparent reduction in the predator population, particularly in chemical control. During the subsequent data collection, 0.8% soybean oil significantly registered the highest number of predators with 1.95 and 4.10 at 7 and 10 DAS, respectively. At 15 DAS, 0.4% soybean oil + 0.8% liquid dishwashing significantly recorded the highest number of predators having 3.65, while no population of predators was observed in the chemical control during this period.

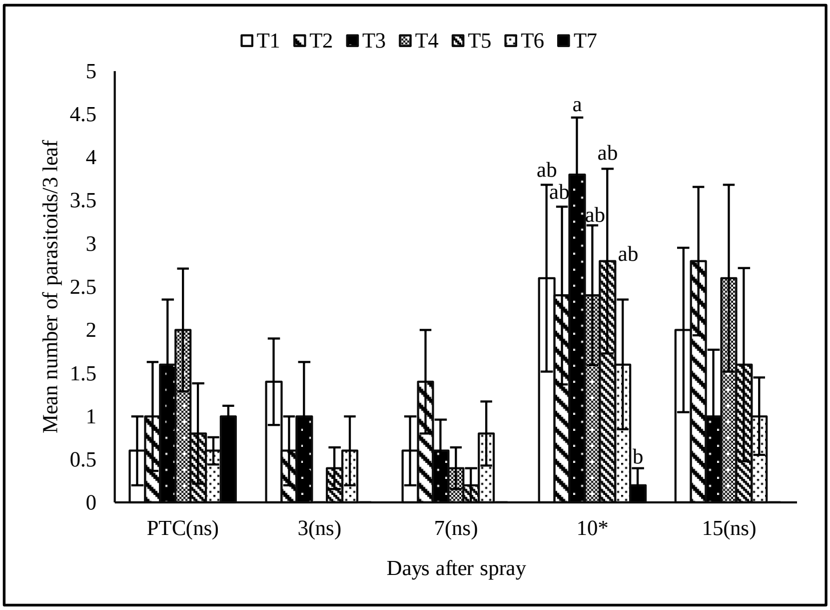


Untreated control (T1), soybean oil (0.8%) (T2), liquid dishwashing (1.6%) (T3), neem oil (1.6%) (T4), soybean oil (4%) + liquid dishwashing (0.8%) (T5), neem oil (0.8%) + liquid dishwashing (0.8%) (T6) and chemical control (T7); PTC – pre-treatment count, (*) significant at 0.05, (**) significant at 0.01 and ns – non-significant; bars with the same letters did not differ statistically after Tukey's test.

Figure 1. Effects of soybean oil, neem oil and liquid dishwashing on the population of predators in guava on different days after spraying under field conditions

3.2.2 Effects of the Treatments on Parasitoids

Insect parasitoids are minute to medium-sized insects that lay eggs either on or in the host's body. When hatched, it will feed inside its host's body ultimately killing it. The most observed insect parasitoid of the spiralling whitefly is the *Encarsia guadeloupe* (Hymenoptera: Aphelinidae), which is a pupal parasitoid. In the present study, there was no significant difference regarding the number of *E. guadeloupe* at pre-treatment which ranged from 0.6 to 1.6 as shown in Figure 2. Similar results were obtained at 3 and 7 DAS wherein a statistically equal number of *E. guadeloupe* was found that ranged from 0 to 1.4 and 0 to 1.4, respectively. However, there was an observed reduction of *E. guadeloupe* in these periods when compared with the pre-treatment count. At 7 DAS, 1.6% liquid dishwashing significantly registered the highest number of *E. guadeloupe* with 3.8 over the chemical control. At 15 DAS, no significant variations were found among treatments in terms of the number of *E. Guadeloupe.*



Untreated control (T1), soybean oil (0.8%) (T2), liquid dishwashing (1.6%) (T3), neem oil (1.6%) (T4), soybean oil (4%) + liquid dishwashing (0.8%) (T5), neem oil (0.8%) + liquid dishwashing (0.8%) (T6) and chemical control (T7); PTC – pre-treatment count, (*) significant at 0.05, (**) significant at 0.01 and ns – non-significant; bars with the same letters did not differ statistically after Tukey's test.

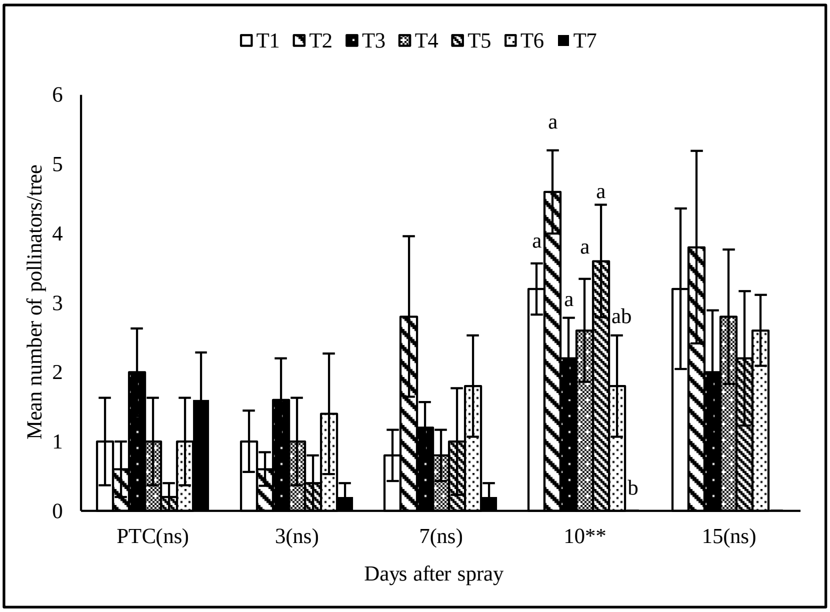
Figure 2. Effects of soybean oil, neem oil and liquid dishwashing on the emergence of *A. dispersus* parasitoids in guava on different days after spraying under field conditions

3.2.3 Effects of the Treatments on Pollinators

Pollinators are insects that pollinate crops to bear their fruits. They are essential because they pollinate approximately 70% of all fruit-bearing plants worldwide (Bartomeus *et al*., 2014). The present study identified the effects of the treatments on pollinators. The number of pollinators recorded during pre-treatment ranged from 0.2 to 2.00 as shown in Figure 3 and was found to be uniformly distributed in the field. At 3 and 7 DAS, no difference was observed among treatments. At 10 DAS, a significant difference was observed wherein 0.8% soybean oil registered the highest number of pollinators. At 15 DAS, a non-significant result was obtained in terms of the number of pollinators.

It was observed that all treatments resulted in a moderate reduction of the number of the natural enemies regardless of their functional guilds and was apparent at 3 and 7 DAS. However, the reductions in natural enemy populations were not similar to the decrease found in the chemical control

(Thiamethoxam), which caused the total mortality of natural enemy populations at 10 and 15 DAS. This reduction in the chemical control was consistently observed until 15 DAS. Meanwhile, the number of natural enemies found in the treatments other than chemical control was noted to recover and even increase at 10 and 15 DAS. This might be due to the lower stability of the soybean oil, liquid dishwashing and neem oil in the treated guava trees that could have resulted in the earlier recovery of the natural enemy population. Additionally, the mortality of the spiralling whitefly as affected by the treatments rarely reached 100%. This could be a factor as there were still hosts available for the predators and parasitoids to consume allowing for their survival. Additionally, soybean oil, liquid dishwashing and neem oil are not neurotoxic pesticides like Thiamethoxam in the present study where almost all natural enemies are highly susceptible when exposed (Esquivel *et al.*, 2020).



Untreated control (T1), soybean oil (0.8%) (T2), liquid dishwashing (1.6%) (T3), neem oil (1.6%) (T4), soybean oil (4%) + liquid dishwashing (0.8%) (T5), neem oil (0.8%) + liquid dishwashing (0.8%) (T6) and chemical control (T7); PTC – pre-treatment count, (*) significant at 0.05, (**) significant at 0.01 and ns – non-significant; bars with the same letters did not differ statistically after Tukey's test.

Figure 3. Effects of soybean oil, neem oil and liquid dishwashing on the pollinators in guava on different days after spraying under field conditions

The present study agreed with the previously reported cases on the effects of less toxic insecticides on natural enemies. Oils extracted from *Piper nigrum* did not have detrimental effects on the spider (*Pardosa pseudoannulata*), a predator of many insect pests (Farid *et al*., 2019). Eucalyptus, cedarwood, camphor and lemongrass oil were also found safe from spiders and mirid bugs in the rice ecosystem (Seni, 2019). Meanwhile, insecticidal soaps did not appear to affect the population of *Encarsia* spp. (Stansly and Liu, 1997) and *Harmonia axyridis* (Kraiss and Cullen, 2008). Applying neem-based products also failed to cause significant mortality to the predatory ladybird beetles, syrphid flies, braconid parasitoids and Trichogramma species (Jayaraj and Regupathy, 1999; Raghuraman and Singh, 1999; Sharma and Kashyap, 2002).

4. Conclusion and Recommendation

The application of 0.8% soybean oil, 1.6% liquid dishwashing and 1.6% neem oil, including their combinations, had varying effects in reducing the eggs, nymphal and adult populations of the spiralling whitefly in guava. The average field efficacy of these treatments ranged from 75.50 to 93.50%. Furthermore, these treatments had no substantial adverse effects on the natural enemy complex in the guava field. Therefore, possible integration of these treatments with other pest management strategies such as cultural management and habitat modification schemes is recommended for future works that will determine the compatibility of these technologies. It is also recommended to repeat this study with more than two seasons and more experimental trees per replicate to gather more data, which will further support the present results. Lastly, these treatments must also be trialed against other insect pest species such as the silverleaf whitefly, aphids, thrips, mealybugs and scale insects to determine their efficacy on these economically important insect pests with careful consideration on the treatments' potential phytotoxic effects.

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