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RESEARCH PAPER

Effect of Kaolin Combined with Mineral Oil on the Field Control of the Citrus Butterfly *Papilio demoleus* (Lepidoptera: Papilionidae)

Atefeh Asadnia CHOOBBASTI[1] Mohammad Reza DAMAVANDIAN[1] Behnam Amiri BESHELI[1]

[1] Sari Agricultural Sciences and Natural Resources University, Crops Sciences Faculty, Plant Protection Department, 48181-68984, Sari, Iran

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Corresponding Author
E-mail:
atefehasadniachoobbasti@gmail.com

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Abstract

The citrus butterfly *(Papilio demoleus* Linnaeus) is one of the most destructive pests of citrus orchards in Iran, particularly in Mazandaran Province. Due to environmental and ecological concerns associated with chemical insecticides, alternative and eco-friendly pest control strategies are urgently needed. This study aimed to evaluate the effectiveness of kaolin and mineral oil, individually and in combination, in comparision with the chemical insecticide abamectin, for the control of *P. demoleus* under field conditions. Two separate experiments were conducted on two-year-old Hashimoto satsuma mandarin trees. The first experiment tested five treatments in a completely randomized design (CRD), including mineral oil (1%), kaolin (3% and 6%) + mineral oil (0.5%), abamectin (0.5%), and an untreated control. The second experiment evaluated three treatments-kaolin (6%) + mineral oil (0.5%), abamectin (0.5%), and control-across five tree groups. The results showed that the combination of 6% kaolin + 0.5% mineral oil was the most effective treatment, significantly reducing the number of eggs and larvae of *P. demoleus* while increasing the number of buds and healthy leaves with compared to the untreated control. In some cases, this combination performed comparably to, or even better than, abamectin, particularly in reducing larval density. Across both experiments, the treatment demonstrated strong pest control performance attributed to the synergistic effect of the two mineral-based components. These findings suggest that the combined use of kaolin and mineral oil provides a sustainable and environmentally friendly alternative to conventional chemical insecticides and should be considered as part of integrated pest management (IPM) strategies for citrus production.

1. Introduction

The lime swallowtail or the citrus butterfly, *Papilio demoleus* Linnaeus (Lepidoptera: Papilionidae), is one of the most serious pests of citrus in most citrus-producing regions of Iran, particularly in Mazandaran Province (Mafi Pashakolaei et al., 2012). This pest was first reported in Iran by Kryukhin in 1947 from the southeastern regions of the country and is believed to have been introduced from India (Behdad, 2002). It causes significant damage to citrus crops in citrus-producing provinces such as Hormozgan, Khuzestan, Fars, Kerman, and Sistan and Baluchestan (Azmayeshfard, 2014). In recent years, it has also been observed in citrus orchards in Mazandaran Province (Damavandian, 2021). Various citrus varieties are considered hosts of this pest, but the most severe damage observed on sour orange, sweet orange, lemon, sweet lime, mandarin, and grapefruit, respectively. Other citrus cultivars such as Citron (*Citrus medica* Linnaeus), Pomelo (*Citrus maxima*), and Bergamot orange (*Citrus bergamia* Risso) can also be attacked and damaged by this pest (Esmaeili et al., 2014; Mafi Pashakolaei, 2021). The damage caused by this insect is primarily associated with its larval stage, during which the larvae feed on the leaves, and in severe infestations, only the midrib remains (Khati and Yadav, 2021). The larvae of *P. demoleus* are considered a serious pest of citrus seedlings (30 to 60 cm in height) and other young citrus trees, capable of destroying entire seedlings in nurseries (Sarada et al., 2014). While larval feeding on older citrus trees primarily targets young leaves, in young trees, it can lead to complete (100%) defoliation (Khati and Yadav, 2021). The use of chemical pesticides as an effective strategy for controlling this pest has been increasingly adopted in developing countries (Hussain and Zahid, 2016). However, the adverse effects of these compounds on non-target organisms, including humans, environmental pollution, and their toxicity to the natural enemies of this pest, have raised significant international concerns (Khati and Yadav, 2021; Sarada et al., 2014). Therefore, replacing chemical pesticides with environmentally friendly and safe alternatives appears to be essential in the integrated management of *P. demoleus*.

Mineral oils, owing to their relatively low adverse effects compared with chemical pesticides, are considered a promising alternative for controlling citrus pests, particularly Lepidopterans (Damavandian and Kiaeian Moosavi, 2014; Damavandian, 2016). Researchs conducted in Iran and abroad show that mineral oils, at various concentrations, are effective in controlling lepidopteran pests such as the citrus leafroller *Archips rosanus* Linnaeus (Lepidoptera: Tortricidae) (Marzban Abbasabadi et al., 2019), the citrus leafminer *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) (Amiri Besheli, 2007, 2008; Damavandian and Kiaeian Moosavi, 2014; Kord Firozjaee and Damavandian, 2017), the plum fruit moth *Grapholita funebrana* Treitschke (Lepidoptera: Tortricidae) (Rizzo et al., 2018), the cotton leafworm *Spodoptera littoralis* Boisduval (Lepidoptera: Noctuidae) (El-Sisi et al., 2019), and other significant lepidopteran pests in apple orchards (Deligeorgidis et al., 2019).

On the other hand, kaolin, a mineral composed of aluminum silicate, has gained considerable attention as a safe and valuable alternative to chemical pesticides in integrated pest management programs, due to its non-toxicity to mammals and lack of harmful environmental impacts (Glenn and Puterka, 2005). Findings from various studies have demonstrated the effectiveness of kaolin application in controlling lepidopteran pests such as the carob moth *Ectomyelois ceratoniae* Zeller (Lepidoptera: Pyralidae) (Aghaei and Hatami, 2015; Moshiri et al., 2011; Mozaheb et al., 2014), the codling moth *Cydia pomonella* Linnaeus (Lepidoptera: Tortricidae) (Farazmand et al., 2023), the grape berry moth *Lobesia botrana* Denis & Schiffermüller (Lepidoptera: Tortricidae) (Neyshabouri, 2018), the gypsy moth *Lymantria dispar* Linnaeus (Lepidoptera: Erebidae) (Cadogan and Sharbach, 2007), and the western tentiform leafminer *Phyllonorycter elmaella* Doganlar & Mutuura (Lepidoptera: Gracillariidae) (Knight et al., 2012). The present study was conducted to comparatively evaluate the effectiveness of the chemical insecticide abamectin and mineral-based compounds such as mineral oil and kaolin, in the field control of the citrus butterfly (*P. demoleus*).

2. Materials and Methods

This study was conducted through two separate experiments in a two-year-old citrus orchard planted with the early-maturing Japanese mandarin cultivar *Hashimoto satsuma*, grafted onto sour orange (*Citrus aurantium*) rootstock. The orchard covered approximately 1.5 hectares and was located in Miandorood County, Mazandaran Province, northern Iran, at 36°47′N latitude and 53°12′E longitude, with an elevation of 17 meters below sea level. The trees were spaced 4 meters apart from north to south and 5 meters apart from east to west (5 × 4 m). Irrigation was applied through a drip system, and fertigation was used for seedling nutrition throughout the growing season. Meteorological data of the study area during the experimental period (June to November 2023), based on the records from the Sari (Dasht-e-Naz Region) Meteorological Station, are presented in Table 1. Solar months were converted to their corresponding Gregorian months.

Table 1. Meteorological data of the study area during the research period based on the records from Sari (Dasht-e-Naz Region) Meteorological Station.

Month (Gregorian)	Temperature (°C)	Total precipitation (mm)	Mean relative humidity (%)
June	25.8	24.4	71
July	26.9	15.1	70
August	29.0	0.0	66
September	26.2	28.2	67
October	20.9	151.7	73
November	19.0	59.0	74
Mean	24.4	50.8	70

2.1. Experiment I: Field evaluation of mineral compounds and abamectin

This experiment was conducted using a completely randomized design (CRD) with five treatments and four replications. The treatments were i) Mineral oil (95% Emulsifiable Oil, Abgineh Shimi Azarbaijan Co., Tabriz, Iran) at 1% (1 L per 100 L of water); ii) Kaolin (*Sepidan*®, 95% WP, Kimia Sabzavar Co., Tehran, Iran) at 3% (3 kg per 100 L of water) + mineral oil at 0.5% (0.5 L per 100 L of water), iii) Kaolin at 6% (6 kg per 100 L of water) + mineral oil at 0.5%; iv) Abamectin (1.8% EC, Moshkfam Fars Chemical Co., Shiraz, Iran) at 0.5% (0.5 L per 100 L of water), and v) Control (no pest management intervention).

Each replication consisted of four adjacent trees arranged in a square pattern. To minimize treatment interference, two tree rows were left between replicates. For the combined treatments, mineral oil (0.5%; 0.5 L per 100 L of water) and kaolin (3% or 6%; 3 or 6 kg per 100 L of water) were mixed with water and thoroughly homogenized. Equal volumes (10 L each) of the prepared solutions were combined to obtain a total of 20 L. The mixtures were applied using a 20-L Mitsubishi sprayer (Model XF-20M14A, Mitsubishi Co., Japan). Each tree received 437 mL of spray solution at a pressure of 4.5 bar. The first application of treatments was performed on June 21, 2023, marking the start of the experimental period. Mineral oil treatment were applied every three weeks, while the kaolin + mineral oil combinations were reapplied every 7 to 10 days, depending on the appearance of new buds. In addition, the abamectin insecticide treatment was applied in two stages during the season, on June 21 and September 16, 2023, according to the manufacturer's recommendations. In each sampling session, a total of 16 trees (4 trees per treatment × 4 replications) were assessed per treatment, amounting to 80 trees in total. The first sampling was conducted on July 19, 2023, and subsequent samplings were carried out every 20 days. The final sampling took place on November 20, 2023, resulting in seven sampling rounds during the study period. During each sampling round, data were collected on the number of buds, healthy leaves, damaged leaves, and *P. demoleus* eggs and larvae. The same trees were monitored throughout the experiment, and following each assessment, all detected eggs, larvae, and pupae were removed from the foliage to ensure that subsequent counts represented only new infestations.

2.2. Experiment II: Comparative field assessment of kaolin–mineral oil combination and abamectin

This experiment was arranged in a completely randomized design (CRD) with three treatments and five replications. The treatments were i) Kaolin at 6% + mineral oil at 0.5%, ii) Abamectin at 0.5‰ (0.5 L per 100 L of water), and iii) Control (no pest management intervention).

For the experimental setup, 15 rows of citrus trees were selected, each row consisting of 21 trees. These rows were divided into five groups, each comprising three adjacent rows. Within each group, the three treatments were randomly assigned to the rows. The preparation of the combined treatments followed the same procedure as in the Experiment I, and applications were performed using the same sprayer under identical conditions. As in Experiment I, the initial treatment was applied on June 21, 2023, marking the start of the experimental period. Treatments were subsequently applied at the same frequency and on the same dates as in Experiment I. At each sampling interval, three trees were randomly selected from each row in every group (a total of nine trees per group), resulting in 45 trees sampled per round. The first sampling was conducted on July 19, 2023, and subsequent samplings were performed at 20-day intervals. The final sampling occurred on November 20, 2023, for a total of seven sampling rounds.

During each sampling, the number of buds, healthy and damaged leaves, and *P. demoleus* eggs and larvae were recorded. Unlike the Experiment I, each tree in this trial was sampled only once throughout the study. Furthermore, pest stages (eggs and larvae) were not removed after sampling. Consequently, new trees were selected for evaluation in each round, and this procedure was repeated until the conclusion of the experiment.

2.3. Statistical analysis

Data from both experiments were analyzed using analysis of variance (ANOVA) in SAS software (Version 9.3; SAS Institute, 2017). Mean comparisons among treatments were conducted using Duncan's multiple range test (DMRT). Graphical representations of treatment comparisons were created with Microsoft Excel 2007.

3. Result and Discussion

3.1. Experiment I: Field evaluation of mineral compounds and abamectin

The ANOVA results (Table 2) indicated that the treatments had a statistically significant effect ($p < 0.01$) on all evaluated parameters including number of buds, healthy and damaged leaves, and *P. demoleus* eggs and larvae throughout the sampling period of Experiment I (Table 2). Mean comparison revealed that the highest number of buds and healthy leaves per tree occurred in the treatment with 6% kaolin + 0.5% mineral oil, showing statistically significant differences. The

Table 2. Analysis of variance (ANOVA) results for the effect of treatments on number of buds, healthy and damaged leaves, and *Papilio demoleus* eggs and larvae throughout the sampling period of Experiment I.

Variable	Source of variation	Df	Sum of squares	Mean square	F-value
Number of buds	Treatment	4	689.91	172.48	6.74**
	experimental error	30	767.70	25.59	
Healthy leaves	Treatment	4	32731.23	8182.81	7.93**
	experimental error	30	30956.40	1031.88	
Damaged leaves	Treatment	4	289.87	72.47	4.88**
	experimental error	30	445.50	14.85	
Number of eggs	Treatment	4	372.11	93.03	4.98**
	experimental error	30	560.40	18.68	
Number of larvae	Treatment	4	3.11	0.78	4.09**
	experimental error	30	5.67	0.19	

** : Significant at $p < 0.01$.

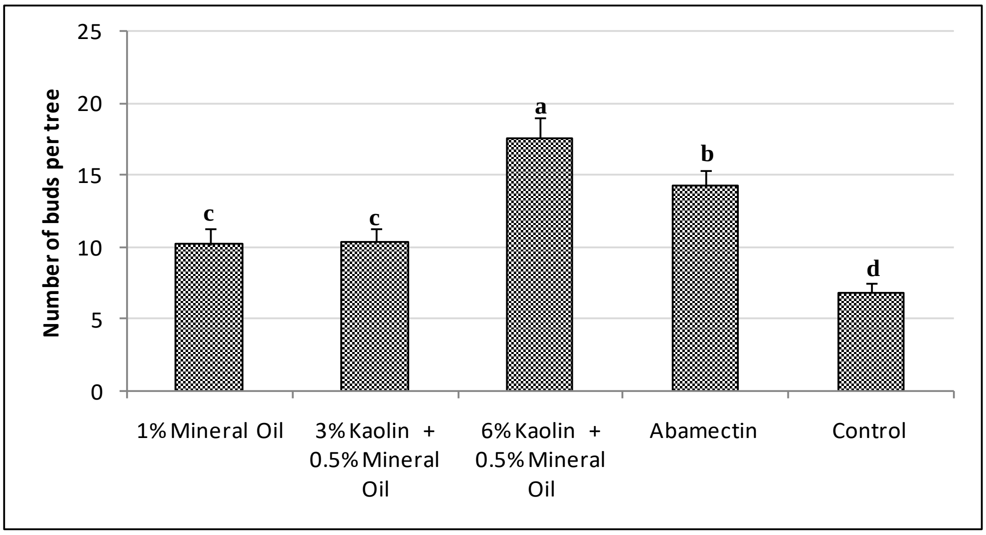

Figure 1. Comparison of mean number of buds per tree under the different treatments throughout the sampling period of Experiment I (Different letters above the bars indicate significant differences according to Duncan's multiple range test, p<0.05).

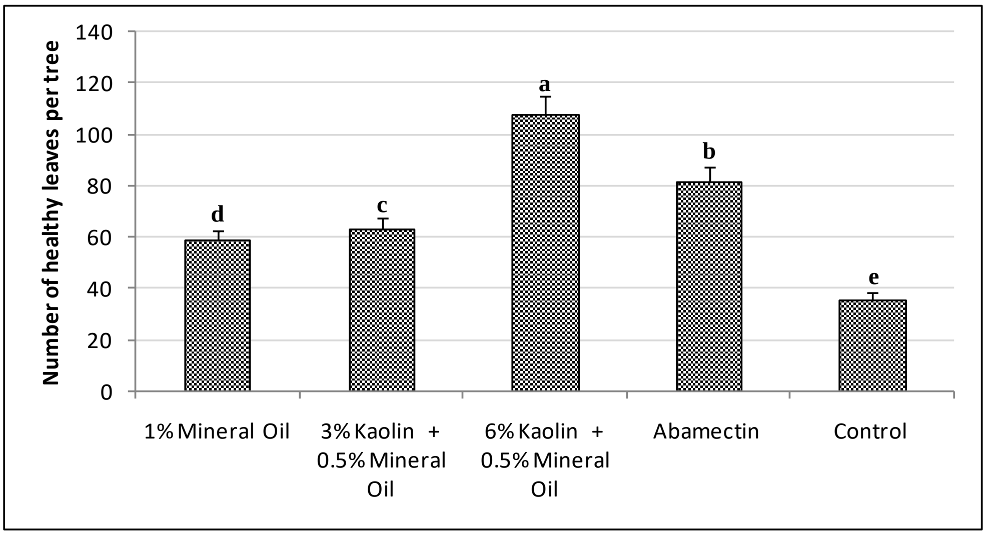

Figure 2. Comparison of mean number of healthy leaves per tree under the different treatments throughout the sampling period of Experiment I (Different letters above the bars indicate significant differences according to Duncan's multiple range test, p < 0.05).

corresponding means were 17.63 buds and 107.46 healthy leaves per tree, respectively (Figures 1 and 2). The lowest number of damaged leaves was observed in trees treated with 6% kaolin + 0.5% mineral oil, with a mean of 5.56 leaves per tree, showing a statistically significant difference only compared to the control (Figure 3). The lowest density of *P. demoleus* eggs was also recorded in trees receiving the same treatment, with a mean of 1.54 eggs per tree, and did not differ significantly from the 3% kaolin + 0.5% mineral oil treatment (Figure 4). Similarly, the lowest larval population of *P. demoleus* was observed in trees treated with 6% kaolin + 0.5% mineral oil, with a mean of 0.20 larvae per tree, which was significantly lower than all other treatments (Figure 5).

3.2. Experiment II: Comparative field assessment of kaolin–mineral oil combination and abamectin

3.2.1. Group I

The analysis of variance for Group I indicated that the applied treatments had a significant effect on all measured variables at the 1% probability level (Table 3). Mean comparison revealed that the highest number of buds and healthy leaves, as well as the lowest number of damaged leaves and pest eggs, were recorded in the 6% kaolin + 0.5% mineral oil treatment, with means of 38.72 buds, 250.62 healthy leaves, 19.33 damaged leaves, and 1.71 eggs per tree, respectively (Table 3). In contrast, the lowest number of *P. demoleus* larvae, with a mean of 0.24 larvae per tree, was observed in trees treated with abamectin, which did not differ significantly from the 6% kaolin + 0.5% mineral oil treatment (Table 3).

3.2.2. Group II

Analysis of variance for Group II indicated that the applied treatments had a statistically significant effect on the number of buds at the 5% probability level, and on all other variables at the 1% probability level (Table 4). Mean comparison showed that the

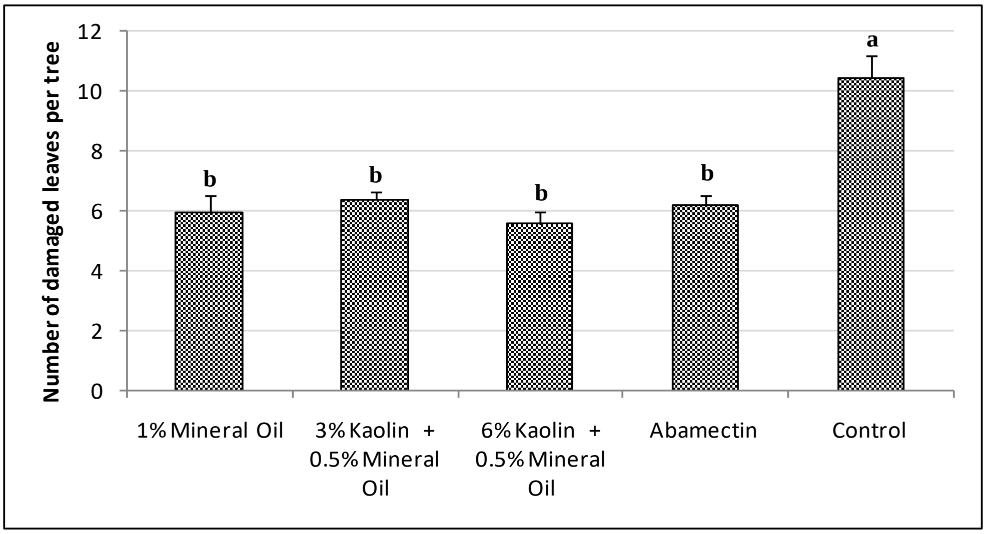

Figure 3. Comparison of mean number of damaged leaves per tree under the different treatments throughout the sampling period of the Experiment I (Different letters above the bars indicate significant differences according to Duncan's multiple range test, $p < 0.05$).

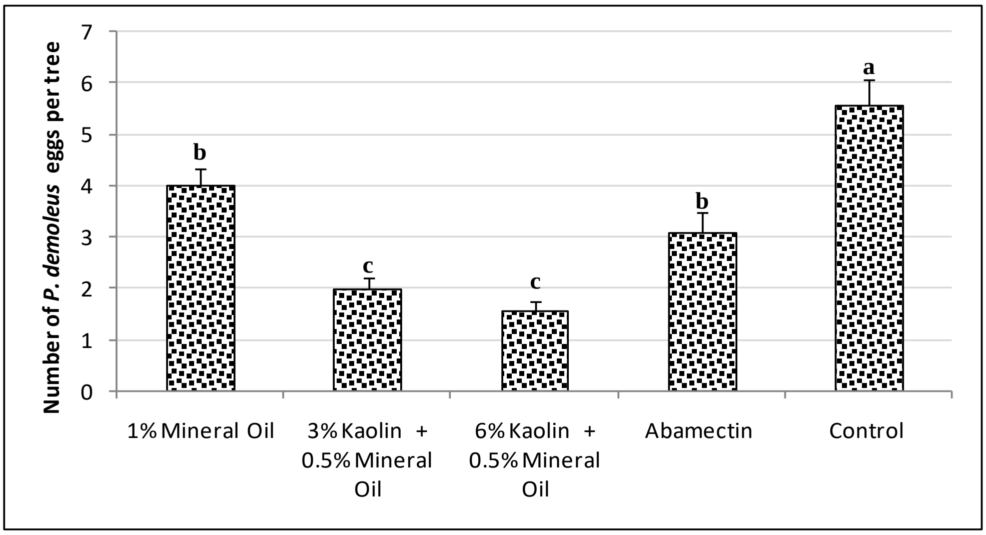

Figure 4. Comparison of mean number of *P. demoleus* eggs per tree under the different treatments throughout the sampling period of Experiment I (Different letters above the bars indicate significant differences according to Duncan's multiple range test, $p < 0.05$).

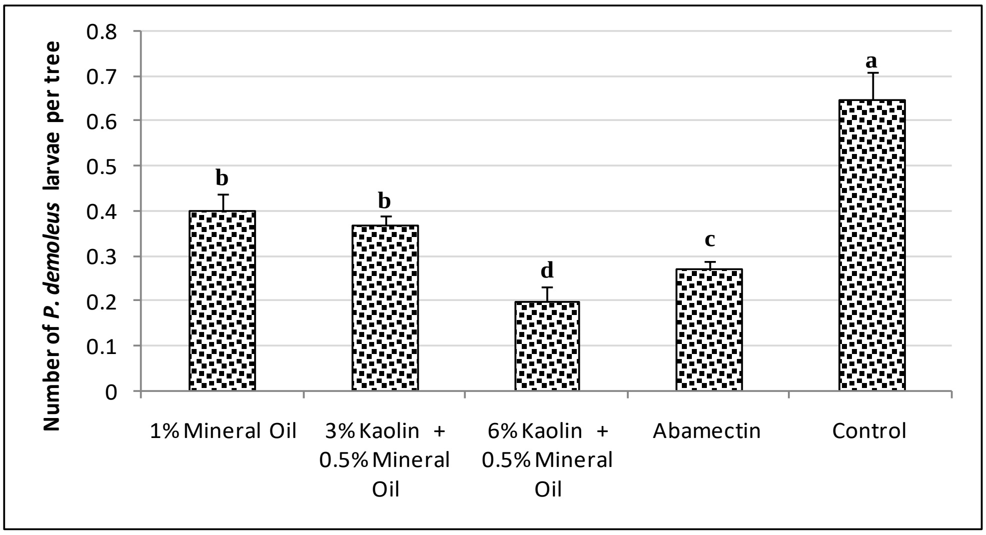

Figure 5. Comparison of mean number of *P. demoleus* larvae per tree under the different treatments throughout the sampling period of Experiment I (Different letters above the bars indicate significant differences according to Duncan's multiple range test, $p < 0.05$).

Table 3. Analysis of variance and mean comparison of treatments for the measured variables in Group I throughout the sampling period of Experiment II.

Treatment	Number of buds‡	Number of healthy leaves	Number of damaged leaves	Number of pest eggs	Number of pest larvae
6% Kaolin + 0.5% Mineral Oil	38.72 a	250.62 a	19.33 c	1.71 c	0.47 b
Abamectin	27.05 b	158.75 b	34.29 b	3.29 b	0.24 b
Control	21.24 c	123.24 c	56.10 a	5.71 a	0.95 a
F-value	8.55**	9.33**	10.22**	6.32**	6.25**

**: Significant at $p < 0.01$.

‡Means within each column followed by different letters are significantly different (Duncan's multiple range test).

Table 4. Analysis of variance and mean comparison of treatments for the measured variables in Group II throughout the sampling period of Experiment II.

Treatment	Number of buds‡	Number of healthy leaves	Number of damaged leaves	Number of pest eggs	Number of pest larvae
6% Kaolin + 0.5% Mineral Oil	32.38 a	206.86 b	16.62c	2.09 c	0.09 b
Abamectin	32.33 a	224.38 a	27.86 b	3.76 b	0.29 b
Control	18.43 b	125.19 c	50.67 a	5.05 a	0.86 a
F-value	4.93*	9.53**	10.83**	6.18**	7.05**

**: Significant at $p < 0.01$.

‡Means within each column followed by different letters are significantly different (Duncan's multiple range test).

highest number of buds—32.38 and 32.33 buds per tree—occurred in the 6% kaolin + 0.5% mineral oil and abamectin treatments, respectively, with no significant difference between them; However, both treatments differed significantly from the control (Table 4). The highest number of healthy leaves was recorded in trees treated with abamectin, with a mean of 224.38 leaves per tree, showing a statistically significant difference. Conversely, the lowest number of damaged leaves, pest eggs, and larvae was observed in trees treated with 6% kaolin + 0.5% mineral oil, with means of 16.62, 2.09, and 0.09 per tree, respectively; However, the larval population did not differ significantly between this treatment and abamectin (Table 4).

3.2.3. Group III

Analysis of variance for Group III indicated that the applied treatments had a statistically significant effect on all measured variables at the 1% probability level (Table 5). Mean comparison revealed that the highest number of buds and healthy leaves, along with the lowest number of damaged leaves and pest eggs, were observed in the 6% kaolin + 0.5% mineral oil treatment, with statistically significant differences. The respective means were 43.95 buds, 290.00 healthy leaves, 18.81 damaged leaves, and 1.67 eggs per tree (Table 5). The lowest number of *P. demoleus* larvae was observed in trees treated with abamectin, with a mean of 0.29 larvae per tree, which did not differ significantly from the 6% kaolin + 0.5% mineral oil treatment (Table 5).

3.2.4. Group IV

Analysis of variance for Group IV (Table 6) showed that the treatments applied to tangerine trees had a statistically significant effect on the

Table 5. Analysis of variance and mean comparison of treatments for the measured variables in Group III throughout the sampling period of Experiment II.

Treatment	Number of buds‡	Number of healthy leaves	Number of damaged leaves	Number of pest eggs	Number of pest larvae
6% Kaolin + 0.5% Mineral Oil	43.95 a	290.00 a	18.81 c	1.67 c	0.28 b
Abamectin	35.24 b	167.62 b	36.72 b	3.71 b	0.24 b
Control	19.76 c	103.00 c	60.24 a	6.24 a	1.00 a
F-value	9.45**	11.21**	12.61**	6.82**	6.54**

**: Significant at $p < 0.01$.
‡Means within each column followed by different letters are significantly different (Duncan's multiple range test).

Table 6. Analysis of variance and mean comparison of treatments for the measured variables in Group IV throughout the sampling period of Experiment II.

Treatment	Number of buds‡	Number of healthy leaves	Number of damaged leaves	Number of pest eggs	Number of pest larvae
6% Kaolin + 0.5% Mineral Oil	24.76 a	161.29 a	12.86 c	2.00 b	0.14 b
Abamectin	19.72 b	122.61 b	15.71 b	2.57 b	0.00
Control	13.86 c	76.95 c	29.62 a	3.72 a	0.67 a
F-value	8.82**	10.06**	6.68**	4.48*	5.70*

* = significant at $p < 0.05$; ** = significant at $p < 0.01$.
‡Means within each column followed by different letters are significantly different (Duncan's multiple range test).

Table 7. Analysis of variance and mean comparison of treatments for the measured variables in Group V throughout the sampling period of Experiment II.

Treatment	Number of buds‡	Number of healthy leaves	Number of damaged leaves	Number of pest eggs	Number of pest larvae
6% Kaolin + 0.5% Mineral Oil	20.43 a	100.00 a	7.57 c	1.24 c	0.14 b
Abamectin	16.86 b	92.33 b	17.33 b	2.67 b	0.05 b
Control	11.19 c	54.43 c	27.86 a	4.33 a	1.19 a
F-value	8.51**	7.85**	13.35**	7.12**	8.78**

**: Significant at $p < 0.01$.
‡Means within each column followed by different letters are significantly different (Duncan's multiple range test).

number of buds, healthy leaves, and damaged leaves at the 1% probability level, and on the number of pest eggs and larvae at the 5% probability level (Table 6). Mean comparison indicated that the highest number of buds (24.76 per tree) and healthy leaves (161.29 per tree), as well as the lowest number of damaged leaves (12.86 per tree), were observed in the 6% kaolin + 0.5% mineral oil treatment, with statistically significant differences compared to the other treatments (Table 6). In addition, the lowest number of pest eggs (2.00 eggs per tree) was recorded in the same treatment, although this was not significantly different from the abamectin. No *P. demoleus* larvae were observed on the leaves of trees treated with abamectin; however, there was no statistically significant difference between this treatment and 6% kaolin + 0.5% mineral oil in terms of larval count (Table 6).

3.2.5. Group V

Analysis of variance for Group V showed that the applied treatments had a statistically significant effect on all measured variables at the 1% probability level (Table 7). Mean comparison indicated that the highest number of buds (20.43 per tree) and healthy leaves (100.00 per tree), as well as the lowest number of damaged leaves (7.57 per tree) and pest eggs (1.24 per tree), were observed in the 6% kaolin + 0.5% mineral oil treatment, with statistically significant differences compared to the other treatments (Table 7). Conversely, the lowest number of *P. demoleus* larvae (0.05 per tree) was recorded in trees treated with abamectin, which did not differ significantly from the 6% kaolin + 0.5% mineral oil treatment (Table 7).

Mineral oils are recognized as an important alternative to synthetic pesticides for the management of agricultural and horticultural pests (Kim et al., 2010). Unlike conventional chemical pesticides, they are considered more environmentally friendly (Helmy et al., 2012) and have therefore received increasing attention as a sustainable option in modern crop protection strategies. In addition to providing effective suppression of a broad range of insect pests , mineral oils help reduce reliance on synthetic chemicals, thereby lowering risks to non-target organisms and minimizing environmental impacts. Consequently, they have become a key component of integrated pest management (IPM) programs for crops worldwide (Damavandian and Kiaeian Moosavi, 2014). Their incorporation into IPM frameworks aligns with global efforts to promote safer, more sustainable agricultural practices while maintaining crop productivity. These compounds offer several advantages, including low toxicity to non-target organisms and natural enemies, ease of application, human safety, lower cost compared to conventional control methods, and a reduced likelihood of resistance development in pest populations (Suma et al., 2009). Their effectiveness arises from multiple mechanisms of action that contribute to insect mortality. These include blocking the spiracles (respiratory openings), forming a thin film over eggs that disrupts gas exchange, and dissolving the waxy outer layer of the insect cuticle, ultimately leading to desiccation and other physiological impairments (Helmy et al., 2012). Such diverse mechanisms enhance their overall efficacy while reducing the risk of resistance development, further underscoring their importance as a sustainable pest management tool.

Numerous studies have confirmed the efficacy of mineral oils against lepidopteran pests. Damavandian and Kiaeian Moosavi (2014) reported that mineral oil concentrations above 0.65% significantly reduced citrus leafminer damage. Marzban Abbasabadi et al. (2019) found that at a 1.5% mineral oil application decreased bud infestation by the citrus bud moth (*A. rosanus*) by approximately 57% compared to the untreated control. Laboratory trials by Rizzo et al. (2018) demonstrated oviposition-deterrent and ovicidal effects of mineral oil against the plum fruit moth (*G. funebrana*) on three plum cultivars. Similarly, El-Sisi et al. (2019) showed that 1-2% mineral oils reduced cotton leafworm (*S. littoralis*) infestations on broccoli, with efficacy ranging of 28.3–75%.

Kaolin has also been demonstrated to be effective against lepidopteran pests, including *E. ceratoniae* (Aghaei and Hatami, 2015; Moshiri et al., 2011; Mozaheb et al., 2014), *C. pomonella* (Farazmand et al., 2023), *L. botrana* (Neyshabouri, 2018), *L. dispar* (Cadogan and Sharbach, 2007), and *P. elmaella* (Knight et al., 2012). Its mode of action involves acting as a repellent and a mechanical barrier that deters feeding and oviposition, contributing to reduced pest infestation (Glenn and Puterka, 2005; Mazor and Erez, 2004). Numerous studies have also confirmed the synergistic effects of kaolin and mineral oils. Darzi et al. (2021) reported that 5% kaolin on early-season mandarin trees reduced the Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) infestation by 79.3% - 98.2%, while 5% kaolin + 0.5% mineral oil reduced infestation by 26.1% - 75.5%. Similarly, Golbahari et al. (2023a, 2023b) demonstrated that 5% kaolin + 5% mineral oil effectively suppressed eggs, nymphs, and adults of the pear psyllid, *Cacopsylla pyricola* Foerster (Hemiptera: Psyllidae) by 57.9 – 86.9% across spring and summer applications. Norouzi Aghamaleki et al. (2024) also reported 5% kaolin + 3% mineral oil in rice fields reduced central shoot death and white panicle incidence caused by the rice stem borer, *Chilo suppressalis* Walker (Lepidoptera: Crambidae) by 83% and 88%, respectively, while oviposition and larval population were reduced by ~77% and >90%, respectively. The results of field Experiment I clearly demonstrated that the combined application of 6% kaolin and 0.5% mineral oil was the most effective treatment for mitigating damage and reducing the population of *P. demoleus* on citrus trees. Across seven sampling intervals, this treatment significantly improved tree health, with a 157% increase in the number of buds and a 204.33% increase in the number of healthy leaves compared to the untreated control. Additionally, the number of damaged leaves decreased by nearly 47% in treated trees. Foliar application of 6% kaolin + 0.5% mineral oil also resulted in a 72.30% reduction in egg numbers and a 69.23% decrease in larval density of *P. demoleus*. These findings highlight the potential of this mineral-based combination as an environmentally friendly and effective alternative to synthetic insecticides for citrus pest management.

Experiment II further confirmed the superior performance of the kaolin + mineral oil treatment across all five experimental groups. In many cases, this treatment matched or even exceeded the efficacy of abamectin. Notably, the kaolin-based treatment consistently resulted in significantly higher number of buds and healthy leaves, as well as lower densities of pest eggs and larvae.

The strong performance of the kaolin + mineral oil treatment can be attributed to the synergistic effects of both components. Mineral oils disrupt insect respiration and physical protection mechanisms (Helmy et al., 2012), while kaolin acts as both a repellent and a mechanical barrier (Glenn and Puterka, 2005; Mazor and Erez, 2004). This dual-action likely contributed to the significant reduction in pest infestation levels observed throughout the experimental period.

Overall, the results of the two experiments indicated that the observed increases in buds and healthy leaves in trees treated with the combined kaolin and mineral oil, as well as with 1% mineral oil alone, were likely associated with reductions in *P. demoleus* egg and larval densities. In Experiment I, the 6% kaolin + 0.5% mineral oil treatment reduced egg and larval populations by 72.3% and 69.2%, respectively, compared to the untreated control. The 3% kaolin + 0.5% mineral oil combination decreased egg and larval numbers by 64.2% and 43.1%, respectively, while application of 1% mineral oil resulted in reductions of 28.1% for eggs and 38.5% for larvae. In Experiment II, conducted on five tree groups, the 6% kaolin + 0.5% mineral oil treatment led to reductions of 46.2–73.2% in egg numbers and 50.5–89.5% in larval populations relative to the control. These findings underscore the strong efficacy of the combined kaolin and mineral oil treatment in suppressing *P. demoleus* populations while simultaneously enhancing tree health.

In Experiment I, 6% kaolin + 0.5% mineral oil was more effective than the chemical insecticide abamectin, reducing the numbers of damaged leaves, eggs, and larvae of *P. demoleus* by 10.6%, 50.2%, and 25.9%, respectively. In the experiment

II, while abamectin was more effective in controlling *P. demoleus* larvae, the 6% kaolin + 0.5% mineral oil treatment outperformed abamectin in reducing leaf damage (by 18.1–56.3%) and egg density (by 22.2–55%). These results indicate that the combined kaolin and mineral oil treatment can serve as an effective and environmentally friendly alternative to chemical insecticides for managing *P. demoleus* in citrus orchards. Economic evaluation further supports the practicality of this approach. In Experiment I, six applications of 1% mineral oil cost 2,100,000 Rials (≈ 3.5 USD), while 12 sprays of 3% kaolin + 0.5% mineral oil and 6% kaolin + 0.5% mineral oil cost 2,560,000 Rials (≈ 4.3 USD) and 3,070,000 Rials (≈ 5.1 USD), respectively, which were lower than two abamectin sprays (4,000,000 Rials; ≈ 6.7 USD). In Experiment II, 12 applications of 6% kaolin + 0.5% mineral oil cost 4,140,000 Rials (≈ 6.9 USD), compared to 5,000,000 Rials (≈ 8.3 USD) for two abamectin sprays.

Considering the environmental risks, non-target toxicity, and potential for resistance associated with chemical insecticides (Khati and Yadav, 2021; Sarada et al., 2014), the kaolin–mineral oil combination represents a promising eco-friendly alternative within IPM programs. Previous studies support their effectiveness against other lepidopteran pests, such as *E. ceratoniae* (Moshiri et al., 2011), *C. pomonella* (Farazmand et al., 2023), and *P. citrella* (Damavandian and Kiaeian Moosavi, 2014). The present study adds to this body of evidence by demonstrating their efficacy against *P. demoleus* in citrus orchard in northern Iran

4. Conclusion

The results of this study demonstrated that the integrated use of kaolin (6%) and mineral oil (0.5%) was highly effective in reducing the population of *Papilio demoleus* in citrus orchards. This treatment significantly lowered the number of pest eggs and larvae, reduced leaf damage, and promoted higher counts of buds and healthy leaves compared to the untreated control. In several variables, its performance was comparable to that of the chemical insecticide abamectin. Given the environmental concerns and risks associated with synthetic pesticides-such as non-target toxicity, resistance development, and ecological contamination-the kaolin + mineral oil combination presents a sustainable and eco-friendly alternative. Its non-toxic nature, compatibility with beneficial organisms, and ease of application make it a valuable component in integrated pest management (IPM) strategies for citrus orchards.

Therefore, it is recommended that mineral-based compounds, particularly kaolin and mineral oil, be incorporated into the IPM programs targeting *P. demoleus* and other lepidopteran pests, especially in regions where chemical pesticide usage is a concern. Future studies can further explore optimization of application intervals and combinations with biological control agents to enhance efficacy and sustainability.

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