



Evaluation of *Artemisia vulgaris* Essential Oil–Kaolin Combinations as Repellents against *Diaphorina citri*

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Abstract

Citrus Vein Phloem Degeneration (CVPD) is a destructive citrus disease associated with *Candidatus Liberibacter asiaticus*, a bacterium belonging to the class α -proteobacteria. Psyllid vectors, primarily *Diaphorina citri*, transmit the pathogen by acquiring the bacterium and inoculating it directly into citrus phloem tissues. This study evaluated the repellency of different concentrations and combinations of kaolin and *Artemisia vulgaris* essential oil against *D. citri*. The research was conducted at the Plant Protection Laboratory and Experimental Field, Faculty of Agriculture, UPN Veteran Yogyakarta. The experiments employed choice and non-choice tests arranged in a completely randomized design. The treatments consisted of different concentrations of *A. vulgaris* essential oil combined with kaolin. The 2% *A. vulgaris* essential oil and 1.5% kaolin combination showed a repellency index of 0.66 against *D. citri* after 12 hours in the non-choice test, indicating a repellent effect. In the choice test, the combination treatment resulted in 6.83–7.66 *D. citri* moving toward untreated twigs during the 20–60 minute observation, suggesting that the repellency was primarily associated with the volatile compounds released from *A. vulgaris* essential oil and was enhanced by the presence of the kaolin film. In the persistence test, repellent activity remained evident one day after application. However, it declined progressively from 60% after 1 day to 7 and 14 days after application, likely due to the volatilization of *A. vulgaris* essential oil. The treatment did not adversely affect citrus growth and even resulted in better growth than untreated plants, although kaolin residue may reduce light intensity received by the plants. These findings indicate that combining *A. vulgaris* essential oil with kaolin has potential as a botanical-based repellent strategy to reduce *D. citri* activity in citrus production.

Keywords: *D. citri*, Repellency, *Artemisia vulgaris*, Essential Oil, Kaolin

INTRODUCTION

Citrus is one of the most widely consumed fruit crops worldwide because of its nutritional and economic value. To meet high demand, citrus production remains an important agricultural activity (Hanif, 2020). Global citrus production is estimated at 45.92 million tons (U.S. Department of Agriculture, Foreign Agricultural Service, 2026), while Indonesia's citrus production reached 2.51 million tons in 2021, down 209,091 tons from the previous year (Badan Pusat Statistik, 2022). Several factors contribute to declining citrus production, including destructive diseases caused by *Candidatus Liberibacter* spp., which are associated with Citrus Vein Phloem Degeneration (CVPD) (Marlina & Mapegau, 2022).

CVPD can substantially reduce citrus production and productivity. Insect vectors, particularly psyllids, can transmit the pathogen from infected to healthy plants (Marlina & Mapegau, 2022). *Candidatus Liberibacter asiaticus* (CLas) is a phloem-limited bacterium transmitted primarily by the Asian citrus psyllid, *Diaphorina citri*, which acquires and inoculates the bacterium during feeding.

Diaphorina citri is a major vector of CLas, while Trioza erytrae is another major vector associated with citrus greening disease in Africa and other regions (Xu et al., 2022). Therefore, managing *D. citri* is an important component of strategies to reduce CLas spread. Conventional synthetic insecticides are widely used to manage *D. citri* in citrus orchards; however, repeated, long-term use can contribute to insecticide resistance.

No curative treatment reliably eliminates CLas from infected citrus plants; therefore,

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management relies largely on preventive and vector-management strategies. Previous studies have shown that *Artemisia vulgaris* essential oil repels insect pests (J. Wang et al., 2006). Kaolin applications have also been reported to reduce agricultural pest infestation (Johnston et al., 2022).

However, information on combining kaolin and *A. vulgaris* essential oil against *D. citri* remains limited, and the effective concentration of this combination has not been established. Therefore, this study aimed to determine the most effective kaolin-*A. vulgaris* essential oil combination for repelling *D. citri*.

LITERATURE REVIEW

Candidatus Liberibacter spp. are associated with Huanglongbing (HLB), also known as Citrus Vein Phloem Degeneration (CVPD), a destructive disease that negatively affects citrus tree health, fruit development, and yield. The term huanglongbing comes from the Chinese expression for “yellow shoot disease,” referring to the characteristic yellow shoots seen in infected citrus trees, not “yellow dragon disease” (Bové, 2006).

HLB was first recognized and studied in southern China, where the disease was associated with characteristic yellow shoots and declining citrus productivity (Dong et al., 2021). Typical symptoms include blotchy leaf mottling, yellow shoots, leaf thickening, defoliation, twig dieback, and tree decline. Infected trees may also produce small, asymmetric, lopsided fruits with abnormal color development, where the stylar end remains green while the peduncular end turns yellow or orange (Bové, 2006; European and Mediterranean Plant Protection Organization, 2026).

Three *Candidatus Liberibacter* species are primarily associated with HLB: *Candidatus Liberibacter asiaticus* (CLas), *Candidatus Liberibacter africanus* (CLaf), and *Candidatus Liberibacter americanus* (CLam). The Asian citrus psyllid, *Diaphorina citri* Kuwayama, primarily transmits CLas and CLam, whereas *Trioza erytreae* is the principal vector of CLaf (da Graça et al., 2016).

Diaphorina citri nymphs and adults feed on citrus phloem tissues and can cause direct damage through feeding. Nymphs also produce waxy secretions that may promote sooty mold development on plant surfaces and interfere with photosynthesis. *Diaphorina citri* acquires CLas during feeding; after that, the bacterium circulates within the insect, including the midgut, hemolymph, and salivary glands, before the insect transmits it to healthy plants during subsequent feeding (Liu et al., 2022).

The transmission of CLas by *D. citri* is persistent and propagative. Adult *D. citri* can also move between citrus orchards, contributing to the vector's spatial spread and potentially spreading the pathogen (Boina et al., 2009). Studies have documented adult *D. citri* movement between orchards, with subsequent reports of movement over distances of approximately 100 m within several days.

Artemisia vulgaris L., commonly known as mugwort, belongs to the family Asteraceae and is widely distributed across Europe, Asia, and North Africa. Its essential oil contains several biologically active volatile compounds, including camphor, 1,8-cineole, β -caryophyllene, and other terpenoids that may contribute to insecticidal and repellent activity (Balasubramani et al., 2018). J. Wang et al. (2006) reported that *A. vulgaris* essential oil repelled adult *Tribolium castaneum*, with stronger repellency at higher doses. Essential oil repellency generally involves volatile compounds that interact with insect olfactory receptors and disrupt host orientation (Poerwanto & Brotodjojo, 2013).

Kaolin-based particle films have been investigated as a non-insecticidal approach for managing arthropod pests. Kaolin is a fine, white aluminosilicate mineral that forms a reflective particle film on plant surfaces after application. The film can interfere with insect host recognition and movement and may reduce settling, probing, and oviposition. In *D. citri*, processed kaolin has been shown to reduce settling and phloem access and to disrupt host-finding ability under field conditions (Miranda et al., 2021).

Despite these benefits, kaolin particle films have several limitations. Kaolin's effectiveness against *D. citri* may decline over time, and repeated applications may be needed to maintain adequate protection during citrus flushing (Miranda et al., 2021).

In addition, kaolin's physiological effects can vary with application concentration, plant species, and environmental conditions, and high concentrations may reduce the availability of

photosynthetically active radiation (Brito et al., 2019). Excessive kaolin deposition may also remain on leaf surfaces and potentially affect stomatal function and gas exchange, indicating that appropriate application rates and film coverage are important considerations (Y. Wang et al., 2022).

Kaolin's white, reflective surface can interfere with psyllids' visual host recognition. Previous studies demonstrated that kaolin particle films reduced *D. citri* settling, disrupted host finding, and reduced access to phloem tissues (Miranda et al., 2021). Thus, kaolin primarily affects insects through visual and physical mechanisms, whereas *A. vulgaris* essential oil contains volatile compounds that can influence insect orientation through olfactory mechanisms.

Because these materials act through different sensory pathways, combining them may provide complementary or enhanced repellent activity against *D. citri*. However, information on the interaction between kaolin and *A. vulgaris* essential oil remains limited, particularly regarding the optimal combination and concentration for repelling *D. citri*. Therefore, evaluating their combined application may provide useful information for developing alternative approaches to *D. citri* management.

RESEARCH METHOD

The research was carried out in a Completely Randomized Design (CRD) from February 2023 to July 2023 at the Plant Protection Laboratory and at the Experimental Garden of the Faculty of Agriculture, UPN "Veteran" Yogyakarta, located in Sleman Regency, Special Region of Yogyakarta. Materials included orange jasmine plants (*Murraya paniculata*), *Artemisia vulgaris* essential oil, kaolin, distilled water, nonyphenol 10, husk charcoal, insulation, adhesive glue, citrus plants, and adult *Diaphorina citri*. The age and sex of individual *D. citri* were not recorded separately.

The tools used are rectangular cage (58 × 58 × 100 cm), plastic cups (4.5 cm high and 6 cm in diameter), round cage (28.5 cm in diameter and 14.5 cm in height), insect net, micro pipette, scissor, erlenmeyer flask 100 ml, pipette 10 ml, timer, 3-armed Y-tube olfactometer with a length of 30 cm and diameter of 10 mm, LED lamp, pot, magnetic stirrer, insect sucking tools and hands prayer.

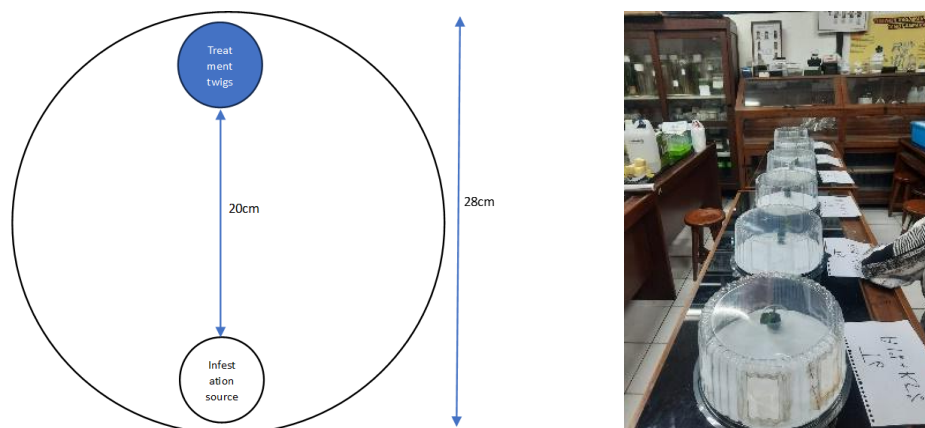


Figure 1. Non-Choice Test with Round Cage

Source: Personal Documentation

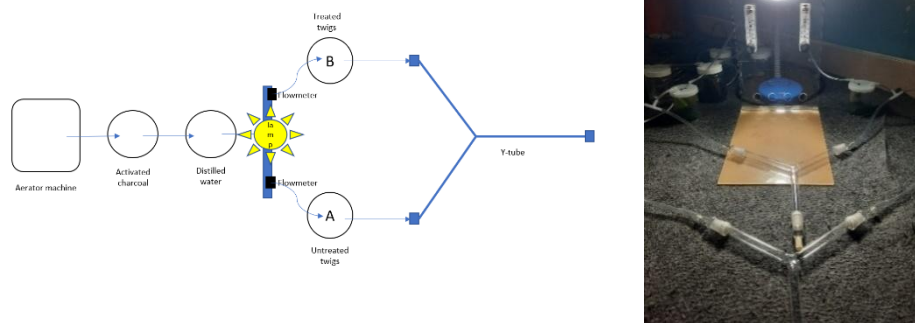


Figure 2. Choice Test with Olfactometer Y-tube

Source: Personal Documentation

Research on choice and non-choice tests was arranged in a Completely Randomized Design (CRD). Non-choice test was conducted with nine treatment of mixture concentration of *A. vulgaris* essential oil and concentration kaolin with three replications, which are T1 = *A. vulgaris* 0.5% + Kaolin 1.5%, T2 = *A. vulgaris* 0.5% + Kaolin 3%, T3 = *A. vulgaris* 0.5% + Kaolin 5%, T4 = *A. vulgaris* 1% + Kaolin 1.5%, T5 = *A. vulgaris* 1% + Kaolin 3%, T6 = *A. vulgaris* 1% + Kaolin 5%, T7 = *A. vulgaris* 2% + Kaolin 1.5%, T8 = *A. vulgaris* 2% + Kaolin 3%, and T9 = *A. vulgaris* 2% + Kaolin 5%.

The non-choice test did not include a concurrent untreated twig control because this assay aimed to assess *D. citri* behavioral distribution in response to the treated citrus twig rather than to compare treated and untreated twigs simultaneously. If the treatment had no repellent effect, the insects were expected to remain responsive to the citrus host and distribute within the arena, including movement toward the treated twig. Thus, the observed distribution of insects among the treated twig, infestation source, and arena was used as a behavioral proxy for repellency, and the resulting repellency index was interpreted accordingly.

The choice test was conducted using a modified three-armed Y-tube olfactometer measuring 30 cm in length and 10 mm in diameter. The selected formulation, *A. vulgaris* essential oil 2% + kaolin 1.5%, was evaluated based on its repellency index in the non-choice test. Six replications were conducted using 10 adult *D. citri* per replicate.

A treated citrus twig and an untreated citrus twig were placed at the ends of the two arms of the Y-tube. Adult *D. citri* were introduced into the choice area, and the numbers of insects moving toward the treated twig, moving toward the untreated twig, and remaining without making a choice were recorded after 20, 40, and 60 min. The data were analyzed using analysis of variance (ANOVA) at a 5% significance level. If significant differences were found, the data were further tested using the Duncan Multiple Range Test (DMRT) at a 5% significance level to determine treatment differences.

The Index of Repellency (IR) was calculated using the formula from [Mazzonetto and Vendramim \(2003\)](#):

$$IR = \frac{2G}{G + P}$$

G: the percentage of insects present in the treated area; P: the percentage of insects present in the untreated area. The IR values were classified as: IR < 1 repellent, IR = 1 neutral, IR > 1 attractant.

The persistence of repellent activity was evaluated using the formulation *A. vulgaris* essential oil 2% + kaolin 1.5%. Citrus twigs were dipped in the treatment formulation. After treatment, the twigs were subsequently placed under open-field conditions. Repellent activity was evaluated at 1, 7, and 14 days after application. At each assessment date, a treated twig and an untreated citrus twig were simultaneously placed at the two arms of the modified Y-tube olfactometer.

Ten adult *D. citri* were introduced per replicate, with six replicates. The numbers of insects moving toward the treated twig, moving toward the untreated twig, and remaining without a choice were recorded at 20, 40, and 60 min after insect introduction. The distribution of *D. citri* between the

treated and untreated twigs was used to evaluate the formulation's repellent activity over the assessment period.

The effect of the selected formulation (*A. vulgaris* essential oil 2% + kaolin 1.5%) on citrus plant growth was evaluated using treated and untreated citrus plants. The treatment used the selected formulation, while aquadest served as the untreated control. Six replications were used for each treatment.

Plant growth was evaluated before treatment and at 7, 14, 21, and 28 days after treatment. The measured variables were the number of leaves, twig length (cm), and leaf length (cm). Measurements were conducted using the same measurement procedure at each observation date.

FINDINGS AND DISCUSSION

Non-choice Test

The non-choice test was conducted by testing all treatment formulations using round cages as a modified environment. In the round cage, there are two cup placement points: the psyllid cup (infestation source) and the citrus twig cup treated with the formulation (treatment twigs).

Preliminary test

Table 1. Average number of *D. citri* that move toward the treatment twigs (0.5ml NP10), the infestation source, the arena, and the dead *D. citri*.

Observation at	Number of <i>D. citri</i>			
	Treatment twigs	Infestation source	Arena	Die
1st hour	0.00 ± 0.00 pA	3.00 ± 0.57 qC	7.00 ± 0.57 rBC	0.00 ± 0.00 pA
2nd hour	0.33 ± 0.33 pA	2.66 ± 0.33 qC	7.00 ± 0.57 rBC	0.00 ± 0.00 pA
3rd hour	1.00 ± 0.57 pAB	2.66 ± 0.33 qC	6.33 ± 0.88 rBC	0.00 ± 0.00 pA
4th hour	1.00 ± 0.57 pqAB	1.66 ± 0.33 qBC	7.33 ± 0.88 rC	0.00 ± 0.00 pA
5th hour	2.33 ± 0.33 rBC	1.33 ± 0.33 qABC	6.33 ± 0.33 tBC	0.00 ± 0.00 pA
6th hour	2.66 ± 0.66 qBC	1.00 ± 0.57 pqAB	6.00 ± 0.33 rABC	0.33 ± 0.00 pA
7th hour	3.66 ± 1.20 qrC	1.33 ± 0.33 pqABC	4.33 ± 0.88 rABC	0.66 ± 0.33 pA
8th hour	3.66 ± 1.20 qrC	0.33 ± 0.33 pA	5.33 ± 0.88 qABC	0.66 ± 0.33 pA
9th hour	5.00 ± 1.15 qC	0.33 ± 0.33 pA	4.00 ± 1.00 qAB	0.66 ± 0.33 pA
10th hour	4.66 ± 0.88 qC	0.33 ± 0.33 pA	4.33 ± 0.88 qABC	0.66 ± 0.33 pA
11th hour	5.66 ± 1.45 qC	0.33 ± 0.33 pA	3.33 ± 1.33 qA	0.66 ± 0.33 pA
12th hour	5.66 ± 1.45 qC	0.33 ± 0.33 pA	3.33 ± 1.33 qA	0.66 ± 0.33 pA

Notes: Numbers followed by the same capital letter within a column and numbers followed by the same lowercase letter within a row are not significantly different according to the DMRT test at the 5% level. Six replications, with 10 adults of *D. citri* per replicate.

The preliminary test showed that adding 0.5 mL of nonylphenol 10 (NP10) to 100 mL of distilled water (approximately 0.5% v/v) did not repel *D. citri*. NP10 was used as a surfactant to disperse the essential oil in distilled water. Kim (2022) described NP10 as a nonionic surfactant primarily used to improve the dispersion of hydrophobic compounds in water, supporting its suitability as an emulsifier rather than as an active repellent. These findings indicate that NP10 is a suitable surfactant for preparing treatment solutions without influencing *D. citri* behavioral responses.

Concentration test

Table 2. Average number of *D. citri* moving towards citrus twigs that have been dipped in the treatment combination of *A. vulgaris* and kaolin mixture after 1-3 hours of application

Observation at	Treatment	Number of <i>D. citri</i>			
		Treatment Twigs	Infestation Source	Arena	Die

1st hour	A 0.5% + K 1.5%	0.00 ± 0.00 pA	4.33 ± 0.88 qA	5.66 ± 0.88 qA	0.00 ± 0.00 pA
	A 0.5% + K 3%	0.66 ± 0.66 pA	1.66 ± 1.00 pA	8.33 ± 0.88 qA	0.00 ± 0.00 pA
	A 0.5% + K 5%	0.00 ± 0.00 pA	1.66 ± 0.88 qA	8.33 ± 0.88 rA	0.00 ± 0.00 pA
	A 1% + K 1.5%	0.00 ± 0.00 pA	3.00 ± 0.57 qA	7.00 ± 0.57 rA	0.00 ± 0.00 pA
	A 1% + K 3%	0.66 ± 0.57 pA	2.00 ± 0.57 qA	7.33 ± 0.66 rA	0.00 ± 0.00 pA
	A 1% + K 5%	0.00 ± 0.00 pA	2.00 ± 0.57 qA	7.66 ± 0.33 rA	0.33 ± 0.33 pA
	A 2% + K 1.5%	0.66 ± 1.15 pA	3.33 ± 1.33 qA	6.00 ± 1.54 qA	0.00 ± 0.00 pA
	A 2% + K 3%	0.33 ± 0.57 pA	3.33 ± 1.33 qA	6.00 ± 1.52 qA	0.33 ± 0.33 pA
	A 2% + K 5%	0.66 ± 0.57 pA	3.66 ± 2.72 pA	5.66 ± 2.84 pA	0.00 ± 0.00 pA
Average		0.33 ± 0.12 U	2.77 ± 0.40 X	8.88 ± 2.13 WX	0.07 ± 0.26 U
2nd hour	A 0.5% + K 1.5%	0.33 ± 0.33 pAB	2.33 ± 0.33 qA	7.33 ± 0.33 rAB	0.00 ± 0.00 pA
	A 0.5% + K 3%	0.66 ± 0.66 pAB	1.00 ± 0.57 pA	8.33 ± 0.88 qB	0.00 ± 0.00 pA
	A 0.5% + K 5%	0.66 ± 0.33 qAB	2.00 ± 0.00 rA	7.33 ± 0.33 sAB	0.00 ± 0.00 pA
	A 1% + K 1.5%	0.33 ± 0.33 pAB	2.66 ± 0.66 qA	7.00 ± 1.00 rAB	0.00 ± 0.00 pA
	A 1% + K 3%	1.00 ± 0.00 qAB	1.66 ± 0.66 qA	7.33 ± 0.66 rAB	0.00 ± 0.00 pA
	A 1% + K 5%	0.00 ± 0.00 pA	1.00 ± 0.57 pA	8.66 ± 0.33 qB	0.33 ± 0.33 pA
	A 2% + K 1.5%	0.66 ± 0.66 pqAB	2.33 ± 0.88 qA	7.00 ± 0.57 rAB	0.00 ± 0.00 pA
	A 2% + K 3%	1.00 ± 0.57 pqAB	2.00 ± 0.57 qA	6.66 ± 0.33 rAB	0.33 ± 0.33 pA
	A 2% + K 5%	1.66 ± 0.66 pqB	3.33 ± 2.30 pqA	5.00 ± 2.00 qA	0.00 ± 0.00 pA
Average		0.70 ± 0.15 U	2.03 ± 0.30 X	7.18 ± 1.61 X	0.07 ± 0.26 U
3rd hour	A 0.5% + K 1.5%	0.66 ± 0.33 pA	2.66 ± 0.88 qA	6.66 ± 0.66 rA	0.00 ± 0.00 pA
	A 0.5% + K 3%	0.66 ± 0.66 pA	0.66 ± 0.66 pA	8.66 ± 0.66 qA	0.00 ± 0.00 pA
	A 0.5% + K 5%	0.66 ± 0.66 pqA	2.00 ± 1.00 qA	7.33 ± 0.88 rA	0.00 ± 0.00 pA
	A 1% + K 1.5%	1.00 ± 0.57 pqA	3.00 ± 1.00 qrA	6.00 ± 1.15 rA	0.00 ± 0.00 pA
	A 1% + K 3%	0.66 ± 0.33 qA	1.33 ± 0.33 qA	8.00 ± 0.00 rA	0.00 ± 0.00 pA
	A 1% + K 5%	0.33 ± 0.33 pA	1.00 ± 0.00 pA	8.33 ± 0.33 qA	0.33 ± 0.33 pA
	A 2% + K 1.5%	0.66 ± 0.66 pA	2.33 ± 1.45 pA	7.00 ± 1.00 qA	0.00 ± 0.00 pA
	A 2% + K 3%	1.66 ± 0.33 pA	2.00 ± 1.00 pA	6.00 ± 1.00 qA	0.33 ± 0.33 pA
	A 2% + K 5%	2.00 ± 0.57 pqA	2.66 ± 1.76 pqA	5.33 ± 2.35 qA	0.00 ± 0.00 pA
Average		0.92 ± 0.17 UV	1.96 ± 0.32 X	7.03 ± 1.87 WX	0.07 ± 0.26 U
4th hour	A 0.5% + K 1.5%	1.33 ± 0.66 pqA	1.66 ± 0.66 qA	7.00 ± 0.00 rA	0.00 ± 0.00 pA
	A 0.5% + K 3%	1.00 ± 0.57 pqA	2.00 ± 1.15 pA	7.00 ± 1.52 qA	0.00 ± 0.00 pA
	A 0.5% + K 5%	2.33 ± 0.88 qA	0.33 ± 0.33 pA	7.33 ± 0.66 rA	0.00 ± 0.00 pA
	A 1% + K 1.5%	1.66 ± 0.33 pqA	2.00 ± 2.00 pqA	6.33 ± 2.18 qA	0.00 ± 0.00 pA
	A 1% + K 3%	1.00 ± 0.00 qA	0.66 ± 0.33 qA	8.33 ± 0.33 rA	0.00 ± 0.00 pA
	A 1% + K 5%	0.66 ± 0.33 pA	1.00 ± 2.00 pA	8.00 ± 0.57 qA	0.33 ± 0.33 pA
	A 2% + K 1.5%	1.00 ± 1.00 pA	0.66 ± 0.33 pA	8.33 ± 1.20 qA	0.00 ± 0.00 pA
	A 2% + K 3%	1.66 ± 0.66 pA	1.66 ± 0.66 pA	6.33 ± 0.88 qA	0.33 ± 0.33 pA
	A 2% + K 5%	2.66 ± 0.88 qrA	1.66 ± 0.88 pqA	5.66 ± 0.88 rA	0.00 ± 0.00 pA
Average		1.48 ± 0.22 VW	1.29 ± 0.28 W	7.14 ± 1.87 X	0.07 ± 0.26 U
5th hour	A 0.5% + K 1.5%	1.33 ± 0.66 qA	0.33 ± 0.33 pqA	8.33 ± 0.33 rB	0.00 ± 0.00 pA
	A 0.5% + K 3%	1.33 ± 0.66 qA	0.00 ± 0.00 pA	8.66 ± 0.66 rB	0.00 ± 0.00 pA
	A 0.5% + K 5%	3.33 ± 0.88 qAB	1.00 ± 0.57 pA	5.66 ± 0.66 qAB	0.00 ± 0.00 pA

	A 1% + K 1.5%	2.66 ± 0.88 qrAB	1.00 ± 1.00 pqA	6.33 ± 1.76 rAB	0.00 ± 0.00 pA
	A 1% + K 3%	1.66 ± 0.33 qAB	0.66 ± 0.33 pA	7.66 ± 0.66 rB	0.00 ± 0.00 pA
	A 1% + K 5%	2.33 ± 0.88 qAB	0.66 ± 0.66 pqA	6.66 ± 0.66 rAB	0.33 ± 0.33 pA
	A 2% + K 1.5%	1.00 ± 1.00 pA	0.66 ± 0.66 pA	8.33 ± 0.88 qB	0.00 ± 0.00 pA
	A 2% + K 3%	4.33 ± 0.88 qB	1.33 ± 0.88 pqA	4.00 ± 1.52 qA	0.33 ± 0.33 pA
	A 2% + K 5%	3.33 ± 0.88 qAB	0.66 ± 0.33 pA	6.00 ± 1.00 rAB	0.00 ± 0.00 pA
Average		2.37 ± 0.30 WX	0.70 ± 0.18 V	6.85 ± 2.07 WX	0.07 ± 0.26 U
6th hour	A 0.5% + K 1.5%	0.66 ± 0.66 pA	0.33 ± 0.33 pA	8.66 ± 0.33 qA	0.33 ± 0.33 pAB
	A 0.5% + K 3%	1.66 ± 0.33 qA	0.00 ± 0.00 pA	8.33 ± 0.33 rA	0.00 ± 0.00 pA
	A 0.5% + K 5%	4.00 ± 1.00 qA	0.33 ± 0.33 pA	5.66 ± 0.66 qA	0.00 ± 0.00 pA
	A 1% + K 1.5%	4.00 ± 1.52 qrA	0.66 ± 0.66 pqA	5.33 ± 2.02 rA	0.00 ± 0.00 pA
	A 1% + K 3%	3.66 ± 0.89 qA	0.33 ± 0.33 pA	6.00 ± 1.15 qA	0.00 ± 0.00 pA
	A 1% + K 5%	3.66 ± 1.45 qA	0.00 ± 0.00 pA	6.00 ± 1.15 qA	0.33 ± 0.33 pAB
	A 2% + K 1.5%	1.33 ± 0.88 pA	0.33 ± 0.33 pA	8.33 ± 0.88 qA	0.00 ± 0.00 pA
	A 2% + K 3%	4.00 ± 2.08 pA	0.33 ± 0.33 pA	5.00 ± 2.64 pA	0.66 ± 0.33 pB
	A 2% + K 5%	4.00 ± 1.52 qA	0.66 ± 0.33 pA	5.33 ± 1.66 qA	0.00 ± 0.00 pA
Average		3.00 ± 0.43 XY	0.33 ± 0.10 UV	6.51 ± 2.48 VWX	0.14 ± 0.36 U
7th hour	A 0.5% + K 1.5%	1.33 ± 1.33 pA	0.33 ± 0.33 pA	8.00 ± 1.00 qA	0.33 ± 0.33 pAB
	A 0.5% + K 3%	2.66 ± 0.88 qrAB	0.66 ± 0.66 pqA	6.66 ± 1.45 rA	0.00 ± 0.00 pA
	A 0.5% + K 5%	5.33 ± 0.33 qB	0.33 ± 0.33 pA	4.33 ± 0.66 qA	0.00 ± 0.00 pA
	A 1% + K 1.5%	3.66 ± 1.42 qAB	0.00 ± 0.00 pA	6.33 ± 1.45 qA	0.00 ± 0.00 pA
	A 1% + K 3%	3.66 ± 0.66 qAB	0.00 ± 0.00 pA	6.33 ± 0.66 rA	0.00 ± 0.00 pA
	A 1% + K 5%	4.00 ± 1.52 qrAB	0.00 ± 0.00 pA	5.66 ± 1.20 qA	0.33 ± 0.33 pAB
	A 2% + K 1.5%	2.00 ± 1.00 qAB	0.66 ± 0.66 pqA	7.33 ± 0.88 rA	0.00 ± 0.00 pA
	A 2% + K 3%	4.66 ± 1.66 pAB	0.66 ± 0.33 pA	4.66 ± 2.08 pA	0.66 ± 0.33 pB
	A 2% + K 5%	5.00 ± 2.00 qAB	0.33 ± 0.33 pA	4.66 ± 2.33 pqA	0.00 ± 0.00 pA
Average		3.59 ± 0.44 XY	0.33 ± 0.11 UV	5.92 ± 2.43 UVWX	0.14 ± 0.36 U
8th hour	A 0.5% + K 1.5%	2.00 ± 1.15 pA	0.00 ± 0.00 pA	7.66 ± 1.20 qA	0.33 ± 0.33 pAB
	A 0.5% + K 3%	2.66 ± 0.88 qrA	0.00 ± 0.00 pA	7.33 ± 0.88 rA	0.00 ± 0.00 pA
	A 0.5% + K 5%	4.33 ± 0.33 qA	0.33 ± 0.33 pAB	5.33 ± 0.33 qA	0.00 ± 0.00 pA
	A 1% + K 1.5%	4.66 ± 2.02 qA	0.00 ± 0.00 pA	5.33 ± 2.02 qA	0.00 ± 0.00 pA
	A 1% + K 3%	4.66 ± 0.88 qA	0.00 ± 0.00 pA	5.33 ± 0.88 qA	0.00 ± 0.00 pA
	A 1% + K 5%	3.33 ± 1.66 pA	0.00 ± 0.00 pA	4.66 ± 2.60 pA	2.00 ± 1.52 pB
	A 2% + K 1.5%	2.00 ± 1.52 pA	0.00 ± 0.00 pA	8.00 ± 1.52 qA	0.00 ± 0.00 pA
	A 2% + K 3%	5.66 ± 1.20 qA	0.66 ± 0.33 pB	3.00 ± 1.73 pqA	0.66 ± 0.33 pAB
	A 2% + K 5%	6.00 ± 2.08 qA	0.00 ± 0.00 pA	4.00 ± 2.08 pqA	0.00 ± 0.00 pA
Average		3.92 ± 0.48 YZ	0.11 ± 0.06 U	5.62 ± 2.85 UVW	0.33 ± 1.00 U
9th hour	A 0.5% + K 1.5%	2.33 ± 1.45 pA	0.00 ± 0.00 pA	7.33 ± 1.45 qA	0.33 ± 0.33 pAB
	A 0.5% + K 3%	2.66 ± 0.88 qrA	0.00 ± 0.00 pA	7.33 ± 0.88 rA	0.00 ± 0.00 pA
	A 0.5% + K 5%	5.66 ± 0.88 qA	0.33 ± 0.33 pA	4.00 ± 0.57 qA	0.00 ± 0.00 pA
	A 1% + K 1.5%	4.66 ± 2.02 qA	0.00 ± 0.00 pA	5.33 ± 2.02 qA	0.00 ± 0.00 pA
	A 1% + K 3%	5.66 ± 1.20 qA	0.00 ± 0.00 pA	4.33 ± 1.20 qA	0.00 ± 0.00 pA
	A 1% + K 5%	3.66 ± 1.33 pA	0.00 ± 0.00 pA	4.33 ± 2.33 pA	2.00 ± 1.52 pB
	A 2% + K 1.5%	2.33 ± 1.45 pA	0.00 ± 0.00 pA	7.66 ± 1.45 qA	0.00 ± 0.00 pA
	A 2% + K 3%	5.66 ± 1.20 qA	0.00 ± 0.00 pA	3.66 ± 1.45 qA	0.66 ± 0.33 pAB

	A 2% + K 5%	6.33 ± 1.85 qA	0.00 ± 0.00 pA	3.66 ± 1.85 qA	0.00 ± 0.00 pA
Average		4.33 ± 0.49 Z	0.03 ± 0.03 U	5.29 ± 2.77 UV	0.33 ± 1.00 U
10th hour	A 0.5% + K 1.5%	3.00 ± 2.08 pqA	0.00 ± 0.00 pA	6.66 ± 2.02 qA	0.33 ± 0.33 pAB
	A 0.5% + K 3%	3.00 ± 0.57 qA	0.00 ± 0.00 pA	7.00 ± 0.57 rA	0.00 ± 0.00 pA
	A 0.5% + K 5%	5.33 ± 0.66 qA	0.66 ± 0.33 pB	4.00 ± 0.57 qA	0.00 ± 0.00 pA
	A 1% + K 1.5%	5.00 ± 1.73 qA	0.33 ± 0.33 pAB	4.66 ± 1.45 qA	0.00 ± 0.00 pA
	A 1% + K 3%	5.66 ± 0.88 qA	0.00 ± 0.00 pA	4.33 ± 0.88 qA	0.00 ± 0.00 pA
	A 1% + K 5%	3.66 ± 1.33 pA	0.00 ± 0.00 pA	4.33 ± 2.33 pA	2.00 ± 1.52 pB
	A 2% + K 1.5%	3.00 ± 1.52 qA	0.00 ± 0.00 pA	7.00 ± 1.52 rA	0.00 ± 0.00 pA
	A 2% + K 3%	5.66 ± 1.20 qA	0.00 ± 0.00 pA	3.66 ± 1.45 qA	0.66 ± 0.33 pAB
	A 2% + K 5%	6.66 ± 1.76 qA	0.00 ± 0.00 pA	3.33 ± 1.76 pqA	0.00 ± 0.00 pA
Average		4.55 ± 0.46 Z	0.11 ± 0.06 U	5.00 ± 2.60 UV	0.33 ± 1.00 U
11st hour	A 0.5% + K 1.5%	3.00 ± 2.08 pqA	0.00 ± 0.00 pA	6.66 ± 2.02 qA	0.33 ± 0.33 pAB
	A 0.5% + K 3%	3.00 ± 0.57 qA	0.00 ± 0.00 pA	7.00 ± 0.57 rA	0.00 ± 0.00 pA
	A 0.5% + K 5%	6.00 ± 0.57 qA	1.00 ± 0.57 qB	3.00 ± 0.00 rA	0.00 ± 0.00 pA
	A 1% + K 1.5%	5.33 ± 2.02 qA	0.00 ± 0.00 pA	4.66 ± 2.02 qA	0.00 ± 0.00 pA
	A 1% + K 3%	5.66 ± 0.88 qA	0.00 ± 0.00 pA	4.33 ± 0.88 qA	0.00 ± 0.00 pA
	A 1% + K 5%	3.66 ± 1.33 pA	0.00 ± 0.00 pA	4.33 ± 2.33 pA	2.00 ± 1.52 pB
	A 2% + K 1.5%	3.00 ± 2.08 pqA	0.00 ± 0.00 pA	7.00 ± 2.08 qA	0.00 ± 0.00 pA
	A 2% + K 3%	5.66 ± 1.20 qA	0.00 ± 0.00 pA	3.66 ± 1.45 qA	0.66 ± 0.33 pAB
	A 2% + K 5%	6.66 ± 1.76 qA	0.00 ± 0.00 pA	3.33 ± 1.76 pqA	0.00 ± 0.00 pA
Average		4.66 ± 0.50 Z	0.11 ± 0.08 U	4.88 ± 2.81 U	0.33 ± 1.00 U
12nd hour	A 0.5% + K 1.5%	3.33 ± 1.85 qrA	0.00 ± 0.00 pA	6.33 ± 1.76 rA	0.33 ± 0.33 pAB
	A 0.5% + K 3%	3.66 ± 1.20 qA	0.00 ± 0.00 pA	6.33 ± 1.20 qA	0.00 ± 0.00 pA
	A 0.5% + K 5%	6.00 ± 0.57 rA	0.66 ± 0.33 pB	3.33 ± 0.33 qA	0.00 ± 0.00 pA
	A 1% + K 1.5%	5.33 ± 2.02 qA	0.00 ± 0.00 pA	4.66 ± 2.02 qA	0.00 ± 0.00 pA
	A 1% + K 3%	5.66 ± 0.88 qA	0.00 ± 0.00 pA	4.33 ± 0.88 qA	0.00 ± 0.00 pA
	A 1% + K 5%	3.66 ± 1.33 pA	0.00 ± 0.00 pA	4.33 ± 2.33 pA	2.00 ± 1.52 pB
	A 2% + K 1.5%	3.33 ± 1.85 qrA	0.00 ± 0.00 pA	6.66 ± 1.85 qA	0.00 ± 0.00 pA
	A 2% + K 3%	5.66 ± 1.20 qA	0.00 ± 0.00 pA	3.66 ± 1.45 qA	0.66 ± 0.33 pAB
	A 2% + K 5%	6.66 ± 1.76 qA	0.00 ± 0.00 pA	3.33 ± 1.76 pqA	0.00 ± 0.00 pA
Average		4.81 ± 0.47 Z	0.07 ± 0.05 U	4.77 ± 2.66 U	0.33 ± 1.00 U

Notes: Numbers followed by the same capital letter within a column and numbers followed by the same lowercase letter within a row are not significantly different according to the DMRT test at the 5% level. Six replications, with 10 adults of *D. citri* per replicate.

After 12 hours of observation, the non-choice test showed that repellent activity decreased gradually, particularly after 4 hours, which may be attributed to the single application. After 12 hours of observation, the combination treatments showed no significant differences. However, within a single treatment, parameters began to differ significantly among the treatment twigs (attractant), infestation source (repellent), and arena (repellent). [Sutardi et al. \(2019\)](#) stated that natural pesticides degrade more easily, so they need to be applied repeatedly.

The *A. vulgaris* 1% + kaolin 5% treatment showed the highest mortality, with 2.00 ± 1.52 *D. citri* individuals recorded as dead at the first hour. However, mortality was not the main focus of this study, so interpret this result carefully. The observed mortality may relate to the essential oil or formulation, but further toxicity tests are needed to confirm this effect. Essential oils contain volatile compounds that can affect insect behavior and survival ([Ismoilov et al., 2020](#)).

The chemical composition of the *A. vulgaris* essential oil used in the present study was not

independently verified by GC-MS. Therefore, the observed repellency cannot be attributed to any specific constituent of the essential oil used in this experiment. Compounds reported in previous studies, including camphor, α -humulene, β -caryophyllene, and β -caryophyllene oxide, are discussed only as possible constituents of *A. vulgaris* essential oil that may contribute to its repellent activity. In the present study, combining *A. vulgaris* essential oil with kaolin showed a repellent effect against *D. citri* by reducing movement toward treated odor sources compared with untreated sources.

Wijaya (2007) noted that *D. citri* is attracted to the color yellow. Kaolin can repel *D. citri* by blocking its vision through host camouflage and masking the odor source. These findings suggest that combining *A. vulgaris* essential oil with kaolin may enhance repellency by disrupting the olfactory and visual cues *D. citri* uses to locate host plants.

Table 3. Repellency index results for each treatment

Treatment	Average <i>D. citri</i>		IR	Notation
	Treatment twig	Arena		
A0.5%+K1.5%	3.33	6.66	0.66	R
A0.5%+K3%	3.66	6.33	0.73	R
A0.5%+K5%	6.00	4.00	1.20	NR
A1%+K1.5%	5.33	4.66	1.06	NR
A1%+K3%	5.66	4.33	1.13	NR
A1%+K5%	3.66	6.33	0.73	R
A2%+K1.5%	3.33	6.66	0.66	R
A2%+K3%	5.66	4.33	1.13	NR
A2%+K5%	6.66	3.33	1.33	NR

Notes: N (neutral); for repellency index value = 1, R (Repellent) for repellency index value < 1, NR (Not Repellent) for repellency index value > 1.

Based on the repellency index calculation, after 12 hours of observation, only four treatments remained repellent. There are treatment A0.5% + K1.5%, A0.5% + K3%, A1% + K5%, and A2% + K1.5%. The increase in the number of *D. citri* that landed on citrus twigs was in line with the decrease in the treatment's repellency against *D. citri*. Sutardi et al. (2019) stated that natural pesticides decompose more easily, so applications need to be repeated.

Choice Test

The choice test was conducted to identify the best treatment formulation based on repellency index. The choice test used a modified Y-tube olfactometer; citrus twigs were placed at the end of the pipe arm, with and without treatment.

Preliminary test

Table 4. Average number of *D. citri* that moved toward citrus, plain, and did not move.

Obesevation	Number of <i>D. citri</i> that go into		
	Citrus	Plain	Not Moving
20 Minutes	3.66 ± 0.66 pqA	4.33 ± 0.33 qA	2.00 ± 0.57 pA
40 Minutes	5.66 ± 1.20 qA	3.00 ± 1.15 pqA	1.33 ± 0.33 pA
60 Minutes	5.66 ± 1.20 qA	3.00 ± 1.15 pqA	1.33 ± 1.52 pA

Notes: Numbers followed by the same capital letter within a column and numbers followed by the same lowercase letter within a row are not significantly different according to the DMRT test at the 5% level. Six replications, with 10 adults of *D. citri* per replicate.

The preliminary choice test with a modified Y-tube olfactometer showed that *D. citri* could discriminate between odor sources on citrus twigs. Thus, the modified Y-tube olfactometer circuit

effectively evaluates concentration mixtures based on host-plant volatiles.

Concentration test

Table 5. Results of *D. citri* movement in the choice test moving towards the untreated twigs, treated twigs (A2%+K1.5%), and not moving

Observation	Number of <i>D. citri</i> go into		
	Treated Twigs	Untreated Twigs	Not Moving
20 Minutes	1.33 ± 0.66 pA	6.83 ± 0.70 qA	1.83 ± 0.84 pA
40 Minutes	1.33 ± 0.61 pA	7.66 ± 0.66 qA	1.00 ± 0.71 pA
60 Minutes	1.33 ± 0.36 pA	7.66 ± 0.47 qA	1.00 ± 0.44 pA

Notes: Numbers followed by the same capital letter within a column and numbers followed by the same lowercase letter within a row are not significantly different according to the DMRT test at the 5% level. Six replications, with 10 adults of *D. citri* per replicate.

The 60-min choice test showed that the combination of 2% *A. vulgaris* essential oil and 1.5% kaolin resulted in 7.66 ± 0.47 *D. citri* adults moving toward the untreated twig, compared with 1.33 ± 0.36 adults moving toward the treated twig and 1.00 ± 0.44 adults remaining without a choice. Based on the total of 10 insects introduced per replicate, the proportion moving toward the untreated twig was 76.6% ($7.66/10 \times 100$), whereas 13.3% moved toward the treated twig and 10.0% remained without making a choice. Terpenoid compounds in *A. vulgaris* repel *D. citri*, and kaolin also masks the aroma of citrus volatiles.

These results are consistent with previous studies showing that kaolin can reduce *D. citri* presence on citrus plants. Ramirez et al. (2018) reported that kaolin clay and calcium carbonate particle films showed repellent characteristics against *D. citri*, particularly by reducing oviposition and psyllid populations on Tahiti lime. Similarly, Pierre et al. (2021) found that white- and red-dyed kaolin particle films reduced Asian citrus psyllid populations and delayed Huanglongbing infection, while also improving citrus growth. In the present study, combining 2% *A. vulgaris* essential oil with 1.5% kaolin also resulted in greater movement of *D. citri* toward the untreated twig than toward the treated twig. However, unlike previous studies, this study combined kaolin with *A. vulgaris* essential oil and evaluated the response mainly through short-term behavioral assays.

Persistence test

Table 6. Average persistence test results after 1 day, 7 days, and 14 days of application

Days	Observation	Number of <i>D. citri</i> go into		
		Treated twigs	Untreated twigs	Not Moving
1	20 Minutes	1.00 ± 0.44 pA	5.50 ± 0.50 rA	3.50 ± 0.61 qC
	40 Minutes	2.33 ± 0.21 qB	6.33 ± 0.21 rA	1.33 ± 0.33 pB
	60 Minutes	3.16 ± 0.30 qB	6.50 ± 0.22 rA	0.33 ± 0.21 pA
7	20 Minutes	5.00 ± 0.00 qA	2.16 ± 0.16 pA	2.83 ± 0.16 pB
	40 Minutes	6.16 ± 0.16 rA	3.50 ± 0.34 qA	0.33 ± 0.21 pAB
	60 Minutes	6.33 ± 0.33 qA	3.66 ± 0.33 qA	0.00 ± 0.00 pA
14	20 Minutes	5.66 ± 0.49 pA	2.00 ± 0.51 pA	2.33 ± 0.71 pB
	40 Minutes	6.83 ± 0.47 qA	2.50 ± 0.56 qA	0.83 ± 0.65 pA
	60 Minutes	7.00 ± 0.44 qA	3.00 ± 0.44 qA	0.00 ± 0.00 pA

Notes: Numbers followed by the same capital letter within a column and numbers followed by the same lowercase letter within a row are not significantly different according to the DMRT test at the 5% level. Six replications, with 10 adults of *D. citri* per replicate.

The persistence assessment showed a clear reversal in *D. citri* preference over time. At 60 min on day 1 after application, 6.50 ± 0.22 insects moved toward the untreated twig, whereas 3.16 ± 0.30 moved toward the treated twig, indicating that the repellent response was still evident one day after application. However, this pattern was reversed by day 7, when 6.33 ± 0.33 insects moved toward the treated twig

compared with 3.66 ± 0.33 toward the untreated twig.

A similar reversal was observed on day 14, with 7.00 ± 0.44 insects moving toward the treated twig and only 3.00 ± 0.44 toward the untreated twig. This loss and reversal of repellency may be associated with the dissipation of volatile compounds from *A. vulgaris* essential oil during outdoor exposure, reducing the olfactory signal responsible for avoidance. In addition, degradation or physical loss of the essential-oil components from the twig surface may have reduced the original repellent stimulus over time. Therefore, under the conditions tested, the formulation showed an observable repellent response after one day, but this response was not maintained at 7 and 14 days after application.

Effect of treatment on the growth of the citrus plant

Table 7. Mean results of citrus twig growth after treatment

Observation	The growth of		
	Number of leaves	Length of twigs (cm)	Length of leaves (cm)
A 2% + K 1.5%			
Before Treatment		1.67 ± 0.66 A	0.80 ± 0.10 A
Days After Treatment	7	8.33 ± 1.02 BC	4.05 ± 0.05 B
	14	8.00 ± 0.73 BC	6.46 ± 0.03 C
	21	11.00 ± 1.91 CD	7.01 ± 0.14 DE
	28	13.16 ± 2.03 D	7.01 ± 0.14 DE
Aquadest			
Before Treatment		2.50 ± 0.80 A	0.98 ± 0.10 A
Days After Treatment	7	6.66 ± 1.02 A	4.15 ± 0.38 B
	14	6.66 ± 1.05 A	6.18 ± 0.32 C
	21	8.33 ± 0.66 BC	7.66 ± 0.27 EF
	28	8.66 ± 0.88 BC	7.71 ± 0.28 E

Notes: Numbers followed by the same capital letter within a column and numbers followed by the same lowercase letter within a row are not significantly different according to the DMRT test at the 5% level. Six replications, with 10 adults of *D. citri* per replicate.

Applying *A. vulgaris* 2% and kaolin 1.5% suggests that the treatment did not adversely affect citrus plant growth. Plant growth increased throughout the observation period after applying the mixture. The growth rate of treated plants was also higher than that of untreated citrus plants.

After citrus plants were treated with *A. vulgaris* essential oil and kaolin, they became more protected from plant-disrupting organisms and showed better growth than untreated plants. Kaolin at mixed concentrations also helps coat the surface of citrus twigs. Kaolin residue coats the citrus twigs with white patches. The kaolin residue patches may inhibit citrus twigs from receiving sunlight.

As a result, treated plants receive less light than untreated plants. [Buntoro et al. \(2014\)](#) stated that light intensity affects physiological processes, which are reflected in plant morphology. High light intensity causes leaf cells to be smaller, thylakoids to cluster, and chlorophyll to decrease, resulting in smaller, thicker leaves.

CONCLUSIONS

Four of the nine combinations of *A. vulgaris* essential oil and kaolin exhibited repellent activity against *D. citri* during host-finding behavior at 12 hours after application. The 2% *A. vulgaris* essential oil + 1.5% kaolin combination showed the lowest repellency index, indicating the strongest repellency. However, its index was statistically comparable to that of the 0.5% *A. vulgaris* essential oil + 1.5% kaolin combination.

Repellent activity declined with increasing time after application, indicating limited persistence of the formulation under the experimental conditions. Therefore, application intervals may need optimization to maintain effective repellency. Applying 2% *A. vulgaris* essential oil + 1.5% kaolin did not

adversely affect citrus growth and resulted in better growth than untreated plants during the observation period. This finding suggests the formulation could be used without compromising citrus plant growth under the tested conditions.

Practically, the combination of *A. vulgaris* essential oil and kaolin may offer an alternative for reducing *D. citri* host-finding activity. However, field validation is needed to determine its persistence and application requirements. The 0.5% *A. vulgaris* essential oil + 1.5% kaolin combination, which showed repellency comparable to the 2% + 1.5% combination, may also offer a lower-concentration option with reduced essential-oil use and formulation cost.

LIMITATIONS & FURTHER RESEARCH

This study has several limitations to consider when interpreting the results. First, the experimental design did not include an untreated twig control, which limits the ability to distinguish treatment effects from responses associated with the test twig itself. Second, the study did not verify the chemical composition of the *A. vulgaris* essential oil by GC-MS, so it could not confirm the specific compounds responsible for the observed repellency.

Third, the study used limited replication, which may reduce the statistical power and generalizability of the findings. Fourth, the experiment involved a single application, and the study did not evaluate the effects of reapplication at different intervals. Fifth, the authors did not fully characterize the provenance and physiological condition of the *D. citri* used in the experiments, which may have contributed to variation in behavioral responses.

Finally, the experiments were conducted under laboratory and greenhouse conditions without open-field validation; consequently, the effects of environmental factors such as rainfall and ultraviolet (UV) exposure on repellency could not be determined. Therefore, field validation is needed to determine whether the observed repellent effects are maintained under natural environmental conditions.

REFERENCES

- Balasubramani, S., Sabapathi, G., Moola, A. K., Solomon, R. V., Venuvanalingam, P., & Bollipo Diana, R. K. (2018). Evaluation of the leaf essential oil from *Artemisia vulgaris* and its larvicidal and repellent activity against dengue fever vector *Aedes aegypti*—An experimental and molecular docking investigation. *ACS Omega*, 3(11), 15657–15665. <https://doi.org/10.1021/acsomega.8b01597>
- Badan Pusat Statistik. (2022). Statistik hortikultura 2021.
- Boina, D. R., Meyer, W. L., Onagbola, E. O., & Stelinski, L. L. (2009). Influence of interplant movement on acquisition and transmission of *Candidatus Liberibacter asiaticus* by the Asian citrus psyllid, *Diaphorina citri* Kuwayama. *Journal of Economic Entomology*, 102(4), 1578–1584.
- Bové, J. M. (2006). Huanglongbing: A destructive, newly-emerging, century-old disease of citrus. *Journal of Plant Pathology*, 88(1), 7–37. <https://doi.org/10.4454/jpp.v88i1.828>
- Brito, C., Dinis, L.-T., Moutinho-Pereira, J., & Correia, C. (2019). Kaolin, an emerging tool to alleviate the effects of abiotic stresses on crop performance. *Scientia Horticulturae*, 250, 310–316. <https://doi.org/10.1016/j.scienta.2019.02.070>
- Buntoro, B. H., Rohlan, R., & Sri, T. (2014). The effect of manure fertilizer dosage and light intensity on growth and yield of zedoary (*Curcuma zedoaria* L.). *Vegetalika*, 3(4), 29–39.
- da Graça, J. V., Douhan, G. W., Halbert, S. E., Keremane, M. L., Lee, R. F., Vidalakis, G., & Zhao, H. (2016). Huanglongbing: An overview of a complex pathosystem ravaging the world's citrus. *Journal of Integrative Plant Biology*, 58(4), 373–387. <https://doi.org/10.1111/jipb.12437>
- Dong, Z., Singh, A. K., Li, X., Riaz, M., Gao, Y., Li, X., Tang, Q., Shi, X., Wang, S., & Huang, C. (2021). Interactions between nutrient and Huanglongbing pathogen in citrus: An overview and implications. *Scientia Horticulturae*, 290, Article 110511. <https://doi.org/10.1016/j.scienta.2021.110511>
- European and Mediterranean Plant Protection Organization. (2026). *Candidatus Liberibacter africanus* (LIBEAF). <https://gd.eppo.int/taxon/LIBEAF/datasheet>
- Hanif, Z. (2020). Pengembangan agribisnis jeruk Nusantara. Balai Penelitian Tanaman Jeruk dan Buah

Subtropika.

- Ismoilov, K., Wang, M., Jalilov, A., Zhang, X., Lu, Z., Saidov, A., Sun, X., & Han, P. (2020). First report using a native lacewing species to control *Tuta absoluta*: From laboratory trials to field assessment. *Insects*, 11(5), Article 286. <https://doi.org/10.3390/insects11050286>
- Johnston, N., Thomson, P., Matthews, L. P., Josh, P., & Xavier, M. (2022). Repelling whitefly (*Bemisia tabaci*) using limonene-scented kaolin: A novel pest management strategy. *Crop Protection*, 154, Article 105905. <https://doi.org/10.1016/j.cropro.2022.105905>
- Kim, S. T. (2022). Nonylphenol. In *Reference module in biomedical sciences*. Elsevier. <https://doi.org/10.1016/B978-0-12-818731-9.00164-0>
- Liu, K., Peng, R., Guo, Z.-Y., Zhang, M.-Z., Huang, J.-W., & Huang, Q.-X. (2022). Comparative microbiome analysis reveals bacterial communities associated with *Candidatus Liberibacter asiaticus* infection in the Huanglongbing insect vector *Diaphorina citri*. *Journal of Asia-Pacific Entomology*, 25, Article 101884. <https://doi.org/10.1016/j.aspen.2022.101884>
- Marlina, I. H., & Mapegau. (2022). Deteksi penularan penyakit CVPD pada jeruk rough lemon menggunakan inokulum dari berbagai jaringan tanaman sakit dengan tingkat gejala yang berbeda. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, 6(1), 11–22. <https://doi.org/10.22437/jiituj.v6i1.19327>
- Mazzonetto, F., & Vendramim, J. D. (2003). Efeito de pós de origem vegetal sobre *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae) em feijão armazenado. *Neotropical Entomology*, 32, 145–149. <https://doi.org/10.1590/S1519-566X2003000100022>
- Miranda, M. P., Eduardo, W. I., Tomaseto, A. F., Volpe, H. X. L., & Luciano, B. (2021). Frequency of processed kaolin application to prevent *Diaphorina citri* infestation and dispersal in flushing citrus orchards. *Pest Management Science*, 77(12), 5396–5406. <https://doi.org/10.1002/ps.6579>
- Pierre, M. O., Monzo, J. S., Jones, M., Etxeberria, E., Gonzalez, P., & Vincent, C. I. (2021). White- and red-dyed kaolin particle films reduce Asian citrus *Diaphorina citri* populations, delay Huanglongbing infection, and increase citrus growth. *Crop Protection*, 150, Article 105792. <https://doi.org/10.1016/j.cropro.2021.105792>
- Poerwanto, M. E., & Brotodjojo, R. R. (2013). Respon parasitoid generalis *Trichogramma japonicum* terhadap senyawa volatil yang dihasilkan tanaman jeruk. In *Prosiding Seminar Nasional Strategi Reduksi dan Adaptasi Perubahan Iklim dalam Bidang Pertanian*.
- Ramirez, G. A., Parra-Peña, G., & Rodríguez, H. D. (2018). Evaluation of the effect of foliar application of kaolin clay and calcium carbonate on populations of *Diaphorina citri* (Hemiptera: Liviidae) in Tahiti lime. *Crop Protection*, 109, 62–71. <https://doi.org/10.1016/j.cropro.2018.01.012>
- Sutardi, T., Elisabeth, S. H., Wahyuni, S., & Wibowo, A. (2019). Botanical pesticide: The prospect of environmentally friendly pest control. *Jurnal Sumberdaya Lahan*, 13(2), 89–101. <https://doi.org/10.21082/jsdl.v13n2.2019.89-101>
- U.S. Department of Agriculture, Foreign Agricultural Service. (2026). Citrus: World markets and trade. <https://apps.fas.usda.gov/psdonline/circulars/citrus.pdf>
- Wang, J., Zhu, F., Zhou, X. M., Niu, C. Y., & Lei, C. L. (2006). Repellent and fumigant activity of essential oil from *Artemisia vulgaris* to *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Journal of Stored Products Research*, 42, 339–347. <https://doi.org/10.1016/j.jspr.2005.06.001>
- Wang, Y., Cao, X., Han, Y., Han, X., Wang, Z., Xue, T., Ye, Q., Zhang, L., Duan, X., Wang, H., & Li, H. (2022). Kaolin particle film protects grapevine cv. Cabernet Sauvignon against downy mildew by forming particle film at the leaf surface, directly acting on sporangia and inducing the defense of the plant. *Frontiers in Plant Science*, 12, Article 796545. <https://doi.org/10.3389/fpls.2021.796545>
- Wijaya, I. N. (2007). Preferensi *Diaphorina citri* Kuwayama (Homoptera: Psyllidae) pada beberapa jenis tanaman jeruk. *Agritrop*, 26(3), 110–116.
- Xu, C., Weaam, A., Sayed, S., Arshad, K., Javed, K., & El-Shorbagy, M. A. (2022). Analysis of Huanglongbing disease model with a novel fractional piecewise approach. *Chaos, Solitons & Fractals*, 161, Article 112316. <https://doi.org/10.1016/j.chaos.2022.112316>