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Research Article

PERFORMANCE OF VARIOUS BOTANICAL EXTRACTS AGAINST *DIAPHORINA CITRI* (HEMIPTERA: LIVIIDAE) INFECTING LEMON UNDER FIELD CONDITIONS

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ABSTRACT

Diaphorina citri is one of the major pests of citrus worldwide, primarily because it vectors the bacterium *Candidatus Liberibacter asiaticus*, the causal agent of huanglongbing. Due to the lack of scientific studies in Sindh addressing its management, the efficacy of various extracts, ethanol, methanol, and water, from ten indigenous plants was evaluated against *D. citri* in a lemon orchard. The plants tested included prickly chaff flower, thorn apple fruits, basil leaves, bitter apple fruits, *Aloe vera* leaves, siris leaves, karir, field dodder, milkweed leaves, and castor bean leaves. All plant extracts were applied at a rate of 4 Kg per acre. Three sprays were conducted during the study, with observations recorded at 24-h intervals over seven days to assess the effectiveness of the botanical extracts against *D. citri*. The ethanol and methanol extracts of basil, bitter apple, and milkweed were found to be the most effective, whereas field dodder and castor bean were the least effective. Water extracts of all plants were comparatively less effective than their corresponding ethanol and methanol extracts. Over time, the effectiveness of all extracts decreased. At the end of the week, the maximum corrected reductions in *D. citri* populations, calculated using Abbott's formula, were 87.72%, 86.67%, and 85.66% for ethanol basil, methanol basil, and methanol bitter apple extracts, respectively. Based on these findings, it is recommended that ethanol extracts of either basil or bitter apple be incorporated into the integrated management of *D. citri* in citrus orchards.

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INTRODUCTION

Diaphorina citri is recognized as a significant insect pest of citrus trees worldwide, serving as a vector for Huanglongbing (HLB), also known as citrus greening disease, the most devastating disease affecting citrus crops (Gaire et al., 2022; Rizvi et al., 2023). Both adults and nymphs of *D. citri* feed on the cell sap of young twigs and leaves, leading to twig shrinkage, curling of leaves and fruits, and premature fruit drop (Grafton-Cardwell et al., 2013; Ahmad et al., 2014; Tayyab et al., 2022). Moreover, HLB aggravates the damage caused by *D. citri*, manifesting in symptoms such as stunted tree growth, yellowing and mottling of leaves, and the production of deformed, undersized fruits that lack juice (Bové, 2006; Grafton-Cardwell et al., 2013; Hall et al., 2013; Dong et al., 2023). Severe infestations of *D. citri* can result in the death of entire citrus trees (Zaka et al., 2010; Rizvi et al., 2019; Dong et al., 2023). Since 2005, *D. citri* and HLB have devastated the citrus industries of major producers such as China, Brazil, and the USA (Singerman and Rogers, 2020; Rizvi et al., 2023).

To date, no cure has been identified for HLB. Consequently, managing *D. citri* populations remains the only viable approach to mitigate losses (Bové, 2006; Tayyab et al., 2022; Rizvi et al., 2023). Synthetic insecticides from various chemical groups are widely used globally for *D. citri* management (Tang et al., 2021; Yuan et al., 2021). However, repeated insecticide applications have resulted in significant environmental harm, adverse effects on non-target organisms (including humans), pest resurgence, and the development of insecticide resistance in *D. citri* populations (Rizvi et al., 2018; Tian et al., 2020; Chen et al., 2021a). Alarmingly, resistance to organophosphates, pyrethroids, neonicotinoids, carbamates, and diamide insecticides has been documented in *D. citri* populations worldwide, raising serious concerns (Pardo-Melgarejo et al., 2023; Rizvi et al., 2024). Therefore, there is a pressing need to develop alternative, safe, and sustainable control strategies to manage *D. citri* populations in citrus orchards effectively (Tayyab et al., 2022; Rizvi et al., 2023).

Botanical pesticides have long been used as potential alternatives to synthetic insecticides for managing major agricultural and household pests (Kayani et al., 2012; Mukhtar et al., 2013). This is primarily due to their multiple modes of action, biodegradability, and safety for humans, non-target animals, and the environment (Sa'adah et al., 2023). Among botanical pesticides, *Azadirachta indica* and *Nicotiana tabacum* are the most widely utilized for controlling pests in agriculture, horticulture, and households, including *D. citri* (Kamaraj et al., 2018; Azeem et al., 2021; Saeed et al., 2021; Lee et al., 2022).

In addition to these, several other plants have been evaluated for their efficacy in managing *D. citri* populations in citrus orchards, thereby reducing the severity of HLB disease. These include *Delphinium brunonianum* (Rizvi et al., 2024), *Cymbopogon nardus* (Rohim et al., 2023), *Artemisia absinthium* (Rizvi et al., 2023), *Mentha longifolia*, *Melilotus officinalis*, *Nerium indicum*, *Datura alba*, *Salvia officinalis* (Tayyab et al., 2022), and *Ipomoea-periglandula* (Chen et al., 2021b), among others (Rizvi et al., 2018; González-Castro et al., 2019; Rizvi et al., 2019; Reena et al., 2020).

Infestations of *D. citri* have been reported in citrus-growing regions of Pakistan, with most studies focusing on its management (Naeem et al., 2016; Ahmad et al., 2023). However, no systematic research has been conducted on the damage caused by *D. citri* and its management in Sindh province, which is the main lemon-producing region in Pakistan.

The present study aims to evaluate the insecticidal potential of various indigenous plants for reducing *D. citri* populations in a lemon orchard. The findings will assist local growers in Sindh by providing environmentally friendly, cost-effective pest management solutions using locally available plants, thereby reducing dependence on synthetic insecticides and improving the quality and yield of lemons.

MATERIALS AND METHODS

Collection and preparation of plant materials

The indigenous plants evaluated against *D. citri* were prickly chaff flower (*Achyranthes aspera* Linn.), thorn apple fruits (*Dhatura alba* Linn., Syst.), basil leaves (*Ocimum basilicum* Linn.), bitter apple fruits (*Citrullus colocynthis* Linn., Schrad.), Aloe vera leaves (*Aloe barbadensis* Linn., Burm), siris leaves (*Albizia lebbeck* Linn., Benth.), karir (*Capparis decidua* Forssk.), field dodder (*Cuscuta campestris* Yuncker), milkweed leaves (*Calotropis procera* Forst.), castor bean leaves (*Ricinus communis* Linn.), and an untreated control. Fresh samples of all plant materials were obtained from the surrounding areas of the study site, Tandojam, Pakistan. Three types of extracts, ethanol, methanol, and water, were prepared for each plant. The protocols proposed by González-Castro et al. (2019), with slight modifications, were used for the preparation of ethanol and methanol extracts.

Two kilograms of each plant material were thoroughly washed with tap water and air-dried under shade for 48 h in the laboratory of Stored Grain Pests, Department of Entomology, Sindh Agriculture University, Tandojam. Afterward, the plant materials were cut into small pieces, ground to a 40 mm mesh size, sieved, and macerated with 2 L of ethanol and methanol in an Erlenmeyer flask to ensure that the entire plant material was completely submerged. The mixture was left for 24 h in the laboratory. Each plant sample was extracted three times. The obtained mixture of individual botanical extracts was then filtered using Whatman filter paper to obtain a fine extract, which was covered with aluminum foil. Subsequently, the fine mixture was heated in a glass beaker using an electric heater to evaporate the solvents (ethanol and methanol) and obtain semi-dried botanical extracts. These extracts were weighed using an electric balance for calibration. The obtained botanical extracts were stored in an electric refrigerator with proper labeling for future use in the study.

The preparation of water extracts followed the procedure outlined by Kunbhar et al. (2018) with slight modifications. After obtaining small pieces of each plant material, they were submerged in three liters of water in an Erlenmeyer flask and left for 24 h. The mixture was then sieved using fine mesh muslin cloth to obtain the stock solution of each botanical extract. The obtained extracts were stored in the Stored Grain Research Laboratory under a temperature regime of 25 ± 3°C, with proper labeling for future use in the study.

Calibration and application of botanical extracts

The calibration of water used for the experiment was based on 100 L per acre, with each plant material calibrated at a dose of 4 Kg per acre, measured either in milliliters or grams. The number of sprays against *D. citri* was scheduled based on its economic threshold level, estimated at 12 to 15 *D. citri* per flush per plant. Accordingly, three sprays were conducted during the study on April 5, 2023, May 4, 2023, and October 12, 2023.

Experimental design, data collection, and analysis

The experiment was arranged in a Completely Randomized Block Design. The selected orchard was divided into five blocks, with each botanical extract applied to an individual lemon tree. A single botanical extract was used per tree, resulting in each extract being applied to a total of five lemon trees.

Data on the performance of different botanical extracts were collected before the sprays, with subsequent observations recorded 24, 48, and 96 h, as well as one week after each spray. Young flushes (approximately 10-15 mm in length) with at least five young leaves were selected as sample units. For each sprayed lemon tree, five flushes were observed to count the number of adults and nymphs *in situ* using a 10× hand-held lens. These counts were expressed as the number of psyllids per flush (Liang et al., 2023).

The collected data on the performance of various botanical extracts against *D. citri* at different time intervals were analyzed using Analysis of Variance (ANOVA). The Least Significant Difference (LSD) test was employed to separate means with significant differences. Data collected before the sprays were excluded from the ANOVA analysis due to the increasing population of *D. citri* in the control treatment, ensuring more accurate results regarding the effectiveness of the botanical extracts. The analyses were performed using the STATISTIX 8.1 software.

The percentage reduction in the *D. citri* population due to the application of various botanical extracts was calculated using Abbott's formula, as described below:

$$\text{Corrected (\%)} = (1 - \frac{\text{n in T after treatment}}{(\text{n in Co after treatment})} \times 100$$

Where n = psylla population per branch per tree; T = treatment; Co. = Control.

RESULTS

Performance of various botanical extracts in managing *D. citri* on lemon at different observation intervals after the first spray

Table 1 presents the population dynamics of *D. citri* on lemon at different observation intervals following the application of various botanical extracts. Before the spray, no significant difference (F = 0.07, P = 1.000) was observed in the population of *D. citri* across treatments, with counts ranging from 15.81 ± 0.83 psylla per flush (ethanol extract of prickly chaff flower) to 16.64 ± 0.98 psylla per flush (water extract of siris).

After the spray, significant differences in *D. citri* population reduction were observed across intervals: 24 h (F = 22.09, P < 0.001), 48 h (F = 26.27, P < 0.001), 96 h (F = 33.13, P < 0.001), and one week (F = 32.82, P < 0.001). Ethanol extracts were generally more effective than methanol or water extracts, with water extracts showing comparatively lower efficacy. The performance of all botanical extracts improved over time, peaking at 96 h before slightly declining by the end of the week.

At the end of the week, the lowest populations were recorded with ethanol (3.50 ± 0.33 psylla per flush) and methanol (3.92 ± 0.35 psylla per flush) extracts of basil, followed by methanol (4.08 ± 0.32 psylla per flush) and ethanol (4.19 ± 0.32 psylla per flush) extracts of bitter apple. Ethanol (4.58 ± 0.49 psylla per flush) and methanol (4.67 ± 0.51 psylla per flush) extracts of milkweed and thorn apple extracts (ethanol: 4.92 ± 0.46; methanol: 5.00 ± 0.44 psylla per flush) performed similarly to basil extracts. In contrast, field dodder extracts (water: 11.28 ± 1.18; methanol: 10.81 ± 1.25; ethanol: 10.72 ± 1.24 psylla per flush) were the least effective.

At all intervals, the highest *D. citri* populations were recorded in the control, with counts increasing from 20.08 ± 1.08 psylla per flush (24 h) to 28.47 ± 2.38 psylla per flush (one week) (Table 1).

The results on the performance of various botanical extracts in reducing *D. citri* populations, calculated using Abbott's (1925) corrected percentage reduction formula, are presented in Figure 1. Basil, bitter apple, milkweed, and thorn apple were the most effective in reducing *D. citri* populations, while field dodder, castor bean, and prickly chaff flower were the least effective. Among the extraction solvents, ethanol and methanol extracts were more effective than their respective water extracts. After 24 h, the highest reduction in *D. citri* population was observed with the ethanol basil extract (79.67%), reaching 87.71% by the end of the week. Other botanicals with notable reductions included ethanol bitter apple (85.66%), ethanol milkweed (83.90%), ethanol thorn apple (82.73%), methanol aloe vera (79.61%), ethanol karir (76.10%), ethanol siris (73.07%), ethanol chaff flowers (71.61%), ethanol castor bean (68.49%), and ethanol field dodder (62.34%) (Figure 1).

Performance of various botanical extracts in managing *D. citri* on lemon at different observation intervals after the second spray

The results of the second spray of various botanical extracts against *D. citri* in a lemon orchard are presented in Table 2. A similar trend to the first spray was observed, with ethanol and methanol extracts of basil proving the most effective in reducing *D. citri* populations, followed by extracts of bitter apple and milkweed. In contrast, ethanol, methanol, and water extracts of field dodder and castor bean were the least effective.

A steady decline in *D. citri* populations was recorded across all treatments over the week. At one week post-spray, the lowest mean populations were recorded with basil ethanol (2.78 ± 0.27 psylla per flush) and methanol (3.31 ± 0.29 psylla per flush) extracts, followed by bitter apple methanol (3.47 ± 0.32 psylla per flush) and milkweed ethanol (3.69 ± 0.31 psylla per flush) extracts. The performance of milkweed methanol (3.78 ± 0.30 psylla per flush) and bitter apple ethanol (3.86 ± 0.35 psylla per flush) extracts, along with thorn apple methanol (4.22 ± 0.32 psylla per flush) and ethanol (4.25 ± 0.33 psylla per flush) extracts, was comparable to basil extracts.

Field dodder extracts (ethanol: 10.25 ± 0.81; water: 9.69 ± 0.76; methanol: 9.50 ± 0.58 psylla per flush) were the least effective, while control plants had the highest *D. citri* populations at all intervals. Statistical analysis revealed significant differences among plant species ($F = 57.34$, $P < 0.001$) and extract types ($F = 35.41$, $P < 0.001$), with a significant interaction between plants and extracts ($F = 1.81$, $P = 0.0205$).

Following the 2nd spray, the highest reduction in *D. citri* population on lemon was observed with basil, bitter apple, milkweed, and thorn apple extracts at various intervals, while field dodder and castor bean were the least effective. The efficacy of botanical extracts increased over time, with ethanol and methanol extracts outperforming water-based extracts. One week after the 2nd spray, the maximum reduction (85.84%) was recorded with ethanol basil extract, and the minimum (47.73%) with ethanol field dodder extract. Among the other extracts, methanol bitter apple (82.31%), ethanol milkweed (81.16%), methanol thorn apple (78.48%), methanol aloe vera (75.07%), ethanol karir (67.42%), methanol siris (64.46%), ethanol prickly chaff flower (61.19%), ethanol castor bean (58.07%), and methanol field dodder (51.56%) showed varying effectiveness (Figure 2).

Performance of various botanical extracts in managing *D. citri* on lemon at different observation intervals after the third spray

The results of the third spray of various botanical extracts to control *D. citri* population in a lemon orchard are shown in Table 3, which indicates similar trends observed in the first and second sprays. Basil, bitter apple, and milkweed, particularly when extracted in ethanol, were the most effective, followed by methanol and water. A continuous decline in *D. citri* populations was noted across all treatments after the third spray, with the lowest mean population of 2.47 ± 0.18 and 3.19 ± 0.34 psylla per flush recorded in the ethanol basil and bitter apple extract treatments, respectively.

Table 1. Effect of various botanical extracts on *D. citri* population under field conditions following the first spray.

Observation interval	Plant	Extracts		
		Ethanol	Methanol	Water
Before spray	Basil	16.17 ± 0.87 a	16.44 ± 0.92 a	16.33 ± 0.95 a
	Bitter apple	16.28 ± 0.80 a	16.50 ± 0.87 a	16.44 ± 0.93 a
	Milkweed	15.97 ± 0.91 a	16.47 ± 0.99 a	16.06 ± 0.84 a
	Thorn apple	16.11 ± 0.92 a	15.97 ± 0.96 a	16.53 ± 0.94 a
	Aloe vera	16.00 ± 0.80 a	16.22 ± 0.82 a	15.83 ± 0.63 a
	Karir	16.14 ± 0.74 a	15.89 ± 0.79 a	16.44 ± 0.92 a
	Siris	15.94 ± 0.78 a	16.28 ± 0.82 a	16.64 ± 0.98 a
	Prickly chaff flower	15.81 ± 0.83 a	16.28 ± 0.94 a	16.06 ± 0.97 a
	Castor bean	16.11 ± 0.86 a	16.53 ± 0.90 a	16.11 ± 0.91 a
	Field dodder	16.14 ± 0.80 a	16.56 ± 0.94 a	16.00 ± 0.98 a
	Control	15.83 ± 0.41 a		
24-h	Basil	4.08 ± 0.53 l	4.25 ± 0.53 l	6.92 ± 0.70 f-k
	Bitter apple	4.83 ± 0.50 kl	4.72 ± 0.51 kl	7.11 ± 0.67 d-j
	Milkweed	5.11 ± 0.56 jkl	5.22 ± 0.60 jkl	7.06 ± 0.72 e-j
	Thorn Apple	5.36 ± 0.52 i-l	5.47 ± 0.55 i-l	7.17 ± 0.77 d-j
	Aloe vera	6.25 ± 0.54 g-l	6.19 ± 0.55 h-l	7.22 ± 0.78 d-j
	Karir	7.28 ± 0.66 d-j	7.50 ± 0.71 d-i	8.39 ± 0.90 b-h
	Siris	7.94 ± 0.7 1 c-h	8.06 ± 0.75 c-h	9.78 ± 1.02 abc
	Prickly Chaff flower	8.42 ± 0.88 b-g	8.47 ± 0.89 b-f	9.89 ± 0.97 abc
	Castor bean	9.14 ± 0.98 a-e	9.28 ± 1.00 a-d	10.50 ± 1.02 ab
	Field dodder	10.53 ± 1.23 abc	10.56 ± 1.27 ab	10.69 ± 1.34 a
	Control	20.08 ± 1.08		
y48-h	Basil	3.58 ± 0.37 n	3.75 ± 0.40 n	6.61 ± 0.60 h-l
	Bitter apple	4.33 ± 0.37 mn	4.19 ± 0.39 mn	6.92 ± 0.62 g-k
	Milkweed	4.83 ± 0.55 lmn	4.94 ± 0.57 k-n	6.86 ± 0.59 h-k
	Thorn Apple	5.25 ± 0.48 j-n	5.39 ± 0.48 j-n	7.06 ± 0.65 f-j
	Aloe vera	6.00 ± 0.48 i-m	5.92 ± 0.46 i-m	7.11 ± 0.78 f-j
	Karir	7.08 ± 0.65 f-j	7.22 ± 0.67 f-j	8.08 ± 0.74 d-h
	Siris	7.64 ± 0.64 e-i	7.75 ± 0.66 e-i	9.58 ± 0.96 a-e
	Prickly Chaff flower	8.17 ± 0.78 c-h	8.25 ± 0.82 b-h	9.61 ± 0.89 a-e
	Castor bean	8.86 ± 0.88 a-g	8.94 ± 0.89 a-f	10.19 ± 1.03 ab
	Field dodder	10.06 ± 1.11 a-d	10.11 ± 1.15 abc	10.31 ± 1.17 a
	Control	23.42 ± 1.42		
96-h	Basil	3.22 ± 0.33 n	3.50 ± 0.33 mn	6.69 ± 0.60 f-j
	Bitter apple	4.08 ± 0.35 k-n	3.97 ± 0.37 lmn	6.83 ± 0.59 f-j
	Milkweed	4.69 ± 0.51 k-n	4.78 ± 0.53 k-n	6.72 ± 0.61 f-j
	Thorn Apple	5.00 ± 0.47 j-n	5.11 ± 0.48 i-m	7.19 ± 0.68 d-h
	Aloe vera	5.86 ± 0.47 g-k	5.75 ± 0.44 h-l	7.03 ± 0.68 d-h
	Karir	6.83 ± 0.60 f-j	7.00 ± 0.64 e-i	8.00 ± 0.75 b-f
	Siris	7.53 ± 0.57 c-h	7.64 ± 0.57 b-g	9.50 ± 0.92 ab
	Prickly Chaff flower	8.06 ± 0.77 b-f	8.11 ± 0.73 b-f	9.39 ± 0.82 abc
	Castor bean	8.83 ± 0.80 a-e	8.89 ± 0.83 a-d	10.33 ± 0.97 a
	Field dodder	10.42 ± 1.14 a	10.50 ± 1.16 a	10.11 ± 0.90 a
	Control	26.25 ± 2.13		
1-Week	Basil	3.50 ± 0.33 j	3.92 ± 0.35 j	6.78 ± 0.60 fgh
	Bitter apple	4.19 ± 0.32 ij	4.08 ± 0.32 ij	7.06 ± 0.71 efg
	Milkweed	4.58 ± 0.49 ij	4.67 ± 0.51 ij	6.67 ± 0.62 fgh
	Thorn Apple	4.92 ± 0.46 hij	5.00 ± 0.44 hij	7.39 ± 0.67 efg
	Aloe vera	5.94 ± 0.50 ghi	5.81 ± 0.47 ghi	7.28 ± 0.72 efg
	Karir	6.81 ± 0.61 fgh	7.11 ± 0.61 efg	8.44 ± 0.89 c-f
	Siris	7.67 ± 0.58 efg	7.92 ± 0.63 def	9.75 ± 0.92 abc
	Prickly Chaff flower	8.08 ± 0.66 c-f	8.17 ± 0.68 c-f	9.69 ± 0.85 a-d
	Castor bean	8.97 ± 0.90 b-e	9.31 ± 0.94 bcd	10.69 ± 1.06 ab
	Field dodder	10.72 ± 1.24 ab	10.81 ± 1.25 ab	11.28 ± 1.18 a
	Control	28.47 ± 2.38		

*Means with same letters are not significantly different from each other (LSD values: before spray = 2.4249, 24-h = 2.1169, 48-h = 1.9293, 96-h = 1.8055, 1-week = 1.8244, $P < 0.05$).

Table 2. Effect of various botanical extracts on *D. citri* population under field conditions following the second spray.

Observation interval	Plant	Extracts		
		Ethanol	Methanol	Water
Before spray	Basil	14.75 ± 0.77 a	14.47 ± 0.79 a	14.11 ± 0.79 a
	Bitter apple	14.67 ± 0.77 a	14.78 ± 0.75 a	14.50 ± 0.62 a
	Milkweed	14.50 ± 0.55 a	14.39 ± 0.52 a	14.78 ± 0.83 a
	Thorn Apple	14.56 ± 0.80 a	14.11 ± 0.59 a	14.75 ± 0.95 a
	Aloe vera	14.89 ± 0.39 a	14.64 ± 0.40 a	14.25 ± 0.88 a
	Karir	14.36 ± 0.59 a	14.67 ± 0.57 a	14.81 ± 0.94 a
	Siris	14.72 ± 0.68 a	14.19 ± 0.73 a	14.61 ± 0.93 a
	Prickly Chaff flower	14.06 ± 0.71 a	14.53 ± 0.78 a	14.31 ± 0.86 a
	Castor bean	14.89 ± 0.60 a	14.72 ± 0.61 a	14.22 ± 0.79 a
	Field dodder	14.92 ± 0.71 a	14.78 ± 0.73 a	14.50 ± 0.96 a
	Control	14.86 ± 0.61 a		
24-h	Basil	3.19 ± 0.42 n	4.00 ± 0.39 mn	6.61 ± 0.53 h-l
	Bitter apple	4.36 ± 0.41 mn	4.14 ± 0.37 mn	6.86 ± 0.56 g-l
	Milkweed	4.33 ± 0.45 mn	4.36 ± 0.41 mn	6.61 ± 0.54 h-l
	Thorn Apple	5.36 ± 0.52 lm	4.81 ± 0.46 m	7.08 ± 0.68 f-j
	Aloe vera	5.56 ± 0.36 j-m	5.44 ± 0.34 klm	7.11 ± 0.53 f-j
	Karir	6.47 ± 0.42 i-l	7.03 ± 0.50 f-k	7.92 ± 0.69 d-i
	Siris	7.31 ± 0.60 e-i	7.56 ± 0.61 d-i	8.53 ± 0.67 c-f
	Prickly Chaff flower	8.00 ± 0.63 d-i	8.11 ± 0.58 d-h	9.14 ± 0.73 a-d
	Castor bean	8.28 ± 0.59 d-g	8.86 ± 0.49 b-e	9.89 ± 0.81 abc
	Field dodder	10.47 ± 1.04 a	9.89 ± 0.69 abc	10.19 ± 0.91 ab
	Control	16.53 ± 1.23		
48-h	Basil	2.78 ± 0.34 n	3.67 ± 0.31 mn	6.14 ± 0.39 ijk
	Bitter apple	3.92 ± 0.40 mn	3.81 ± 0.36 mn	6.50 ± 0.49 hij
	Milkweed	4.06 ± 0.38l mn	4.08 ± 0.38 lmn	6.22 ± 0.46 ijk
	Thorn Apple	4.64 ± 0.40 lm	4.53 ± 0.37 lm	6.69 ± 0.51 g-j
	Aloe vera	5.36 ± 0.35 jkl	5.00 ± 0.33 klm	6.78 ± 0.42 f-i
	Karir	6.11 ± 0.40 ijk	6.64 ± 0.49 g-j	7.64 ± 0.59 d-h
	Siris	7.19 ± 0.54 e-i	7.22 ± 0.52 e-i	8.14 ± 0.58 c-f
	Prickly Chaff flower	7.44 ± 0.59 e-i	7.89 ± 0.52 d-g	8.83 ± 0.73 a-d
	Castor bean	8.08 ± 0.52 def	8.56 ± 0.46 b-e	9.50 ± 0.70 abc
	Field dodder	10.08 ± 0.87 a	9.61 ± 0.57 ab	9.89 ± 0.80 ab
	Control	17.28 ± 1.33		
96-h	Basil	2.67 ± 0.30 o	3.33 ± 0.28 no	6.00 ± 0.37 ijk
	Bitter apple	3.75 ± 0.36 mno	3.61 ± 0.32 mno	6.25 ± 0.35 hij
	Milkweed	3.89 ± 0.35 mno	3.92 ± 0.35 mno	5.97 ± 0.43 ijk
	Thorn Apple	4.36 ± 0.35 lmn	4.11 ± 0.33 lmn	6.50 ± 0.39 g-j
	Aloe vera	5.28 ± 0.33 jkl	4.83 ± 0.33 klm	6.50 ± 0.40 g-j
	Karir	6.14 ± 0.37 hij	6.44 ± 0.41 hij	7.28 ± 0.51 e-h
	Siris	7.11 ± 0.50 f-i	7.11 ± 0.49 f-i	8.00 ± 0.57 c-f
	Prickly Chaff flower	7.33 ± 0.49 e-h	7.72 ± 0.50 d-g	8.67 ± 0.56 bcd
	Castor bean	8.00 ± 0.46 c-f	8.47 ± 0.46 b-e	9.25 ± 0.59 abc
	Field dodder	10.00 ± 0.78 a	9.44 ± 0.65 ab	9.61 ± 0.75 ab
	Control	18.67 ± 1.88		
1-Week	Basil	2.78 ± 0.27 p	3.31 ± 0.29 op	5.89 ± 0.38 jkl
	Bitter apple	3.86 ± 0.35 nop	3.47 ± 0.32 op	6.31 ± 0.35 ijk
	Milkweed	3.69 ± 0.31 nop	3.78 ± 0.30 nop	6.06 ± 0.39 jkl
	Thorn Apple	4.25 ± 0.33 mno	4.22 ± 0.32 mno	6.64 ± 0.39 g-k
	Aloe vera	5.47 ± 0.39 klm	4.89 ± 0.38 lmn	6.39 ± 0.34 h-k
	Karir	6.39 ± 0.41 h-k	6.58 ± 0.48 g-k	7.44 ± 0.51 e-i
	Siris	7.33 ± 0.58 e-i	6.97 ± 0.54 f-j	7.94 ± 0.58 ef
	Prickly Chaff flower	7.61 ± 0.52 e-h	7.81 ± 0.53 efg	8.50 ± 0.60 b-e
	Castor bean	8.22 ± 0.43 def	8.36 ± 0.39 cde	9.33 ± 0.53 a-d
	Field dodder	10.25 ± 0.81a	9.50 ± 0.58 abc	9.69 ± 0.76 ab
	Control	19.61 ± 2.12		

*Means with same letters are not significantly different from each other (LSD values- before spray = 2.0309, 24-hours = 1.5902, 48-hours = 1.3807, 96-hours = 1.2543, 1-week = 1.2637, $P < 0.05$).

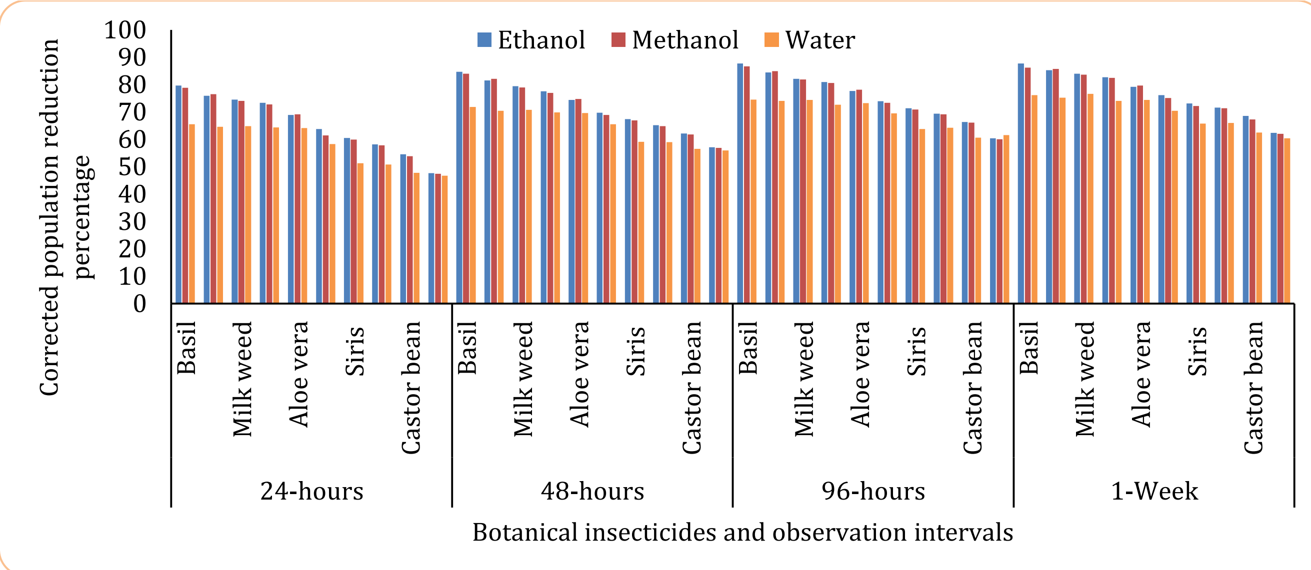

Figure 1. Effect of various botanical extracts on the corrected population reduction percentage of *D. citri* under field conditions following the first spray.

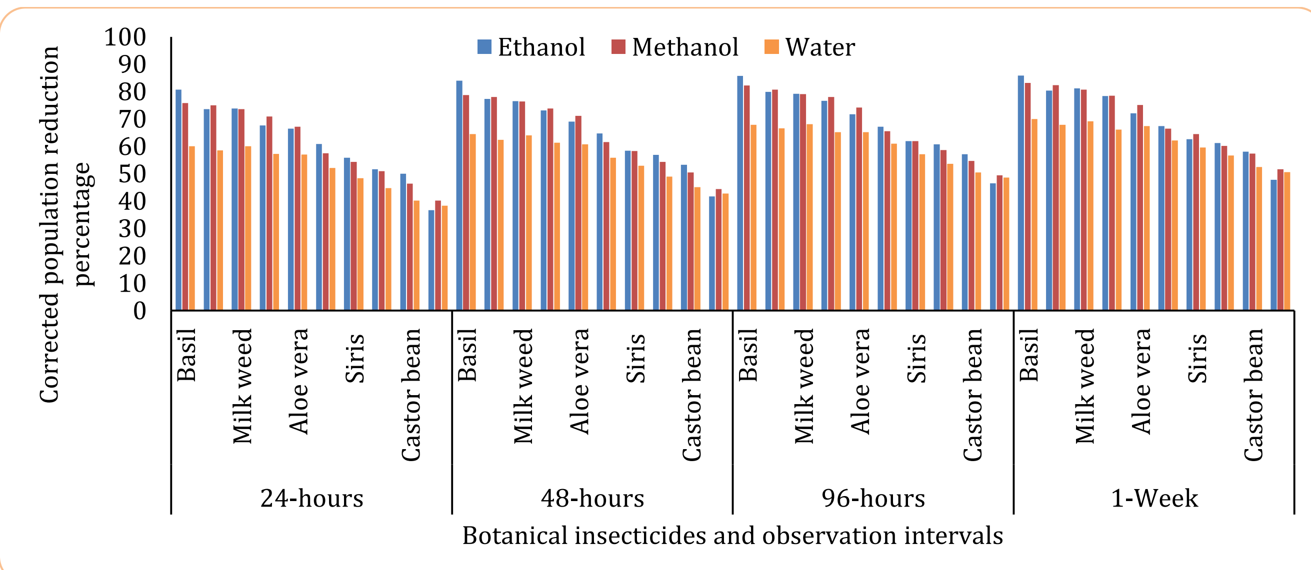

Figure 2. Effect of various botanical extracts on the corrected population reduction percentage of *D. citri* under field conditions following the second spray.

The mean *D. citri* populations in methanol basil (3.22 ± 0.26 psylla per flush), methanol bitter apple (3.39 ± 0.31 psylla per flush), methanol milkweed (3.83 ± 0.30 psylla per flush), and ethanol milkweed (4.06 ± 0.37 psylla per flush) were also comparable to these treatments. All three field dodder extracts (water: 9.67 ± 0.68 psylla per flush, ethanol: 9.33 ± 0.86 psylla per flush, and methanol: 9.33 ± 0.55 psylla per flush) were the least effective in reducing *D. citri* populations. The control lemon treatment exhibited the highest *D. citri* population at various observation intervals (24, 48, 96 h, and one week post-spray) (Table 3). After one week, a highly significant difference was observed in the performance of various botanicals (F = 56.20, P < 0.001) and extracts (F = 39.35, P < 0.001) in controlling the *D. citri* population, while the interaction of extracts and plants showed no significant difference (F = 1.29, P = 0.1868).

Table 3. Effect of various botanical extracts on *D. citri* population under field conditions following the third spray.

Observation interval	Plant	Extracts		
		Ethanol	Methanol	Water
Before spray	Basil	13.97 ± 0.89 a	14.11 ± 0.98 a	14.22 ± 0.83 a
	Bitter apple	13.78 ± 0.85 a	13.92 ± 0.72 a	14.39 ± 0.70 a
	Milkweed	13.56 ± 0.87 a	13.67 ± 0.73 a	13.67 ± 0.93 a
	Thorn Apple	14.00 ± 0.89 a	14.14 ± 0.68 a	13.83 ± 0.91 a
	Aloe vera	14.44 ± 0.97 a	13.84 ± 0.66 a	14.11 ± 0.94 a
	Karir	14.22 ± 0.93 a	14.33 ± 0.73 a	13.97 ± 0.92 a
	Siris	13.94 ± 0.91 a	13.78 ± 0.75 a	13.81 ± 1.03 a
	Prickly Chaff flower	14.03 ± 1.01 a	13.89 ± 0.88 a	14.22 ± 0.87 a
	Castor bean	14.64 ± 0.98 a	14.42 ± 0.77 a	14.00 ± 0.78 a
	Field dodder	14.03 ± 0.90 a	14.17 ± 0.79 a	13.97 ± 1.04 a
	Control	14.36 ± 0.96 a		
24-h	Basil	3.08 ± 0.36 n	3.78 ± 0.39 mn	6.06 ± 0.36 g-k
	Bitter apple	3.69 ± 0.39 mn	3.89 ± 0.33 mn	6.56 ± 0.46 e-j
	Milkweed	4.39 ± 0.45 lmn	4.56 ± 0.42 k-n	6.44 ± 0.44 e-j
	Thorn Apple	4.97 ± 0.39 j-m	5.14 ± 0.42 j-m	7.22 ± 0.48 d-h
	Aloe vera	5.50 ± 0.60 i-l	5.72 ± 0.34 h-l	6.94 ± 0.49 e-i
	Karir	6.39 ± 0.63 e-j	6.92 ± 0.45 e-i	8.00 ± 0.68 b-e
	Siris	7.00 ± 0.54 e-i	7.42 ± 0.58 c-g	8.67 ± 0.68 a-d
	Prickly Chaff flower	7.44 ± 0.72 c-g	7.69 ± 0.49 b-f	9.11 ± 0.64 ab
	Castor bean	8.97 ± 1.02 abc	8.94 ± 0.46 abc	9.86 ± 0.75 a
	Field dodder	10.08 ± 1.17 a	9.83 ± 0.64 a	10.22 ± 0.84 a
	Control	16.75 ± 1.35		
48-h	Basil	2.53 ± 0.28 o	3.22 ± 0.26 no	5.72 ± 0.34 h-k
	Bitter apple	3.42 ± 0.35 no	3.50 ± 0.31 mno	6.22 ± 0.44 ghi
	Milkweed	4.22 ± 0.34 lmn	4.14 ± 0.37 lmn	6.06 ± 0.40 g-j
	Thorn Apple	4.53 ± 0.33 k-n	4.81 ± 0.33 j-m	6.81 ± 0.39 fgh
	Aloe vera	5.28 ± 0.52 i-l	5.22 ± 0.30 i-l	6.56 ± 0.38 f-i
	Karir	6.33 ± 0.61 f-i	6.53 ± 0.41 f-i	7.64 ± 0.53 c-f
	Siris	6.78 ± 0.44 fgh	7.03 ± 0.38 e-h	8.22 ± 0.58 b-e
	Prickly Chaff flower	7.14 ± 0.59 efg	7.31 ± 0.41 d-g	8.78 ± 0.70 abc
	Castor bean	8.81 ± 0.83 abc	8.61 ± 0.39 bcd	9.56 ± 0.63 ab
	Field dodder	9.56 ± 1.02 ab	9.47 ± 0.55 ab	10.00 ± 0.73 a
	Control	17.78 ± 1.39		
96-h	Basil	2.53 ± 0.21 p	3.14 ± 0.20 op	5.58 ±0.30h -l
	Bitter apple	3.14 ± 0.33 op	3.33 ± 0.30 op	5.89 ± 0.32 g-k
	Milkweed	4.14 ± 0.32 mno	3.89 ± 0.33 no	5.94 ± 0.36 f-k
	Thorn Apple	4.36 ± 0.30 l-o	4.72 ± 0.28 k-n	6.61 ± 0.37 e-h
	Aloe vera	5.17 ± 0.38 i-m	5.03 ± 0.31 j-n	6.42 ± 0.33 e-i
	Karir	6.22 ± 0.57 f-j	6.31 ± 0.36 e-i	7.50 ± 0.51 cde
	Siris	6.67 ± 0.41 e-h	6.89 ± 0.43 d-g	8.11 ± 0.53 bcd
	Prickly Chaff flower	7.19 ± 0.57 def	7.19 ± 0.42 def	8.61 ± 0.53 abc
	Castor bean	8.75 ± 0.75 abc	8.47 ± 0.43 bc	9.28 ± 0.55 ab
	Field dodder	9.14 ± 0.94 ab	9.33 ± 0.62 ab	9.81 ± 0.72 a
	Control	18.14 ± 1.61		
1-Week	Basil	2.47±0.18o	3.22±0.26no	5.72±0.33h-k
	Bitter apple	3.19±0.34no	3.39±0.31mno	5.97±0.33g-j
	Milkweed	4.06±0.37lmn	3.83±0.30lmn	5.89±0.34g-j
	Thorn Apple	4.61±0.38klm	4.56±0.29klm	6.64±0.32f-i
	Aloe vera	5.44±0.43ijk	4.78±0.38jkl	6.39±0.30f-i
	Karir	6.39±0.59f-i	6.39±0.42f-i	7.39±0.46d-f
	Siris	6.86±0.47e-h	6.81±0.47e-h	7.94±0.48cde
	Prickly Chaff flower	7.36±0.56def	7.06±0.43efg	8.50±0.53a-d
	Castor bean	8.61±0.69abc	8.33±0.39bcd	9.31±0.47ab
	Field dodder	9.33±0.86ab	9.33±0.55ab	9.67±0.68a
	Control	18.33±1.66		

*Means with same letters are not significantly different from each other (LSD values- before spray = 2.3992, 24-hours = 1.6015, 48-hours = 1.3728, 96-hours = 1.2741, 1-week = 1.2449, $P < 0.05$).

The corrected percentage reduction in *D. citri* due to the third spray of various botanical extracts is presented in Figure 3. Basil, bitter apple, milkweed, and thorn apple were the most effective botanicals, especially when extracted with ethanol or methanol, while their water extracts were the least effective. The effectiveness of all treatments increased with exposure time, peaking one week after application. At the end of the week, the highest reduction (86.52%) was observed with ethanol basil extract, and the lowest (47.25%) with water field dodder extract. Among the other botanicals, notable reductions were recorded with bitter apple in ethanol (82.58%), milkweed in methanol (79.11%), thorn apple in methanol (75.13%), aloe vera in methanol (73.93%), karir in ethanol or methanol (65.15%), siris in methanol (62.85%), prickly chaff flower in methanol (61.49%), castor bean in methanol (54.56%), and field dodder in methanol (49.11%) (Figure 3).

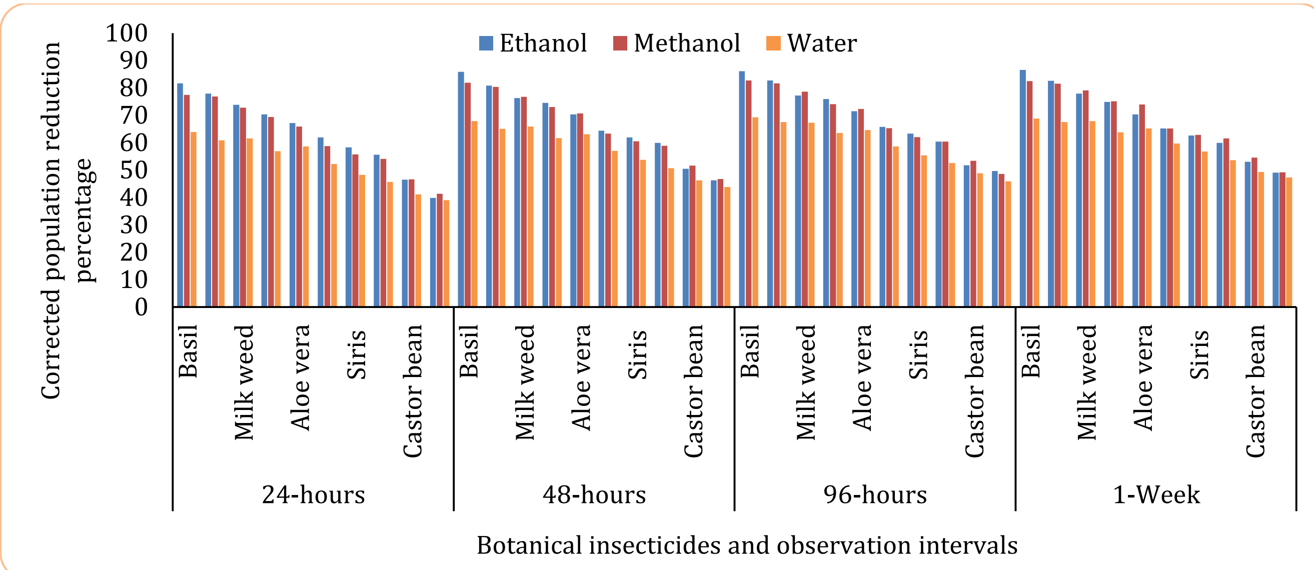

Figure 3. Effect of various botanical extracts on the corrected population reduction percentage of *D. citri* under field conditions following the third spray.

DISCUSSION

The results of all three sprays conducted against *D. citri* in this study demonstrated that all botanical extracts were effective in reducing *D. citri* populations on lemon trees, though their effectiveness varied significantly. Among the plants tested, basil, bitter apple, and milkweed consistently showed the highest effectiveness across all three spray schedules, while field dodder and castor bean were the least effective. Of the solvents used for extraction, ethanol and methanol performed significantly better than water, particularly during the second spray.

The maximum corrected percentage reduction in *D. citri* populations during the three sprays was achieved with ethanol basil extract (87.72%, 85.84%, and 86.52%, respectively). This was followed by methanol bitter apple extract during the first and second sprays (85.66% and 82.31%, respectively) and ethanol extract during the third spray (82.58%), as well as milkweed ethanol extract during the first two sprays (83.90% and 81.16%) and methanol extract during the third spray (79.11%). However, the results for these three plants with ethanol and methanol extracts were not significantly different from one another.

Several studies have investigated various botanicals and their essential oils for managing *D. citri* populations in citrus orchards, highlighting differential modes of action such as pesticidal, repellent, and antifeedant effects (Rizvi et al., 2018, 2019, 2023, 2024). Among these, Borad et al. (2001) evaluated eight botanicals against *D. citri* and citrus leaf miner, finding *A. indica* and *Ipomoea fistulosa* to be comparatively more effective, while *O. sanctum* (from the same genus as basil used in this study) was less effective in managing *D. citri* populations on kagzi lime trees. In contrast, the present study recorded a promising reduction of up to 87.72% in *D. citri* populations with the ethanol extract of basil.

Tayyab et al. (2022) evaluated 40 indigenous plants from Soon Valley, Punjab, for their insecticidal potential against *D. citri* and *Aphis gossypii*, reporting that *Mentha longifolia* was the most effective, causing 93% mortality of *D. citri*, followed by *Melilotus officinalis* (91%), *Nerium indicum* (89%), *D. alba* or thorn apple (88%), and *Salvia officinalis* (81%). The findings for thorn apple (88%) partially align with our study, where up to 80.95% *D. citri* mortality was observed after the first spray. Similarly, another study recorded 31.43% and 60.0% adult mortality of *D. citri* using the spray and leaf dip methods, respectively, and 85.71% nymphal mortality with the leaf dip method (Khan et al., 2013). Khan et al. (2014) also reported a significant reduction in adult and nymphal populations of *D. citri* using thorn apple, comparable to neem and synthetic insecticides.

Milkweed, evaluated in our study, also caused a significant reduction in *D. citri* population (82.12%), aligning partially with Ahmad et al. (2014), who found comparable effectiveness of milkweed (20%) extracts to synthetic insecticides. However, Ahmad et al. (2014) reported no significant effect of various concentrations of thorn apple and neem on *D. citri* populations, which also supports our findings. In our study, ethanol milkweed extracts caused up to 82.12% reduction in *D. citri* population after the first spray.

Although no significant studies specifically address the pesticidal effects of basil against *D. citri*, numerous research studies have demonstrated its pesticidal potential against various agricultural and stored grain pests and diseases (Chowdhary et al., 2018; Bincy et al., 2023). In stored grain pests, the fumigant and contact toxicity of *Ocimum basilicum* and its essential oil have been recorded against *Sitophilus oryzae*, with estragole (85.08%) identified as the major constituent and linalyl acetate (6.75%) as the minor constituent (Bincy et al., 2023). Similarly, the essential oil of *O. basilicum* and its components, estragole and linalool, have been found toxic to *S. zeamais* (Ouko et al., 2017; Moura et al., 2021), *Callosobruchus maculatus* (Kéita et al., 2001), and *Lasioderma serricorne* (Naveen et al., 2021).

Beyond stored grain pests, extracts and essential oils of *O. basilicum* have shown efficacy against agricultural crop pests such as *Spodoptera littoralis* (Benelli et al., 2019), *S. frugiperda* (Silva et al., 2017), *Acanthoscelides obtectus* (Rodríguez-González et al., 2019), and *Bemisia tabaci* (Aslan et al., 2004). Its potential extends to household pests like *Musca domestica* (Benelli et al., 2019) and various mosquito species, including *Culex quinquefasciatus* (Benelli et al., 2019; Jabbar et al., 2022), *Anopheles stephensi* (Maurya et al., 2012), and *Aedes aegypti* (Tennyson et al., 2012; Khan et al., 2021). Moreover, it has demonstrated activity against pathogens like *Colletotrichum gloeosporioides* (Ogbebor et al., 2007) and ticks such as *Rhipicephalus appendiculatus*, *R. microplus*, and *Tetranychus urticae* (Aslan et al., 2004; Martinez-Velazquez et al., 2011).

The pesticidal activities of *O. basilicum* and other *Ocimum* species are attributed to their rich diversity of terpenoids, sesquiterpenes, and flavones (Chowdhary et al., 2018), which exhibit a wide range of effects, including cytotoxicity, insecticidal activity, insect repellency, allelopathy, antimicrobial, antioxidant, and anti-inflammatory properties (Dhifi et al., 2016). Moreover, studies suggest that *O. basilicum* is less toxic to natural enemies and may even act as an attractant, facilitating the management of noxious insect pest populations (Abreu et al., 2021).

Besides basil, ethanol and methanol extracts of bitter apple (*Citrullus colocynthis*) were also effective in reducing the population of *D. citri* on lemon trees. *C. colocynthis* is widely studied for its pesticidal properties against various pests and diseases affecting field crops, household settings, warehouses, and disease vectors (Larbi et al., 2021; Ali et al., 2022; Hassam et al., 2022; El-Halim et al., 2023). However, no systematic studies have yet evaluated its effectiveness against *D. citri*. The fruits of bitter apple are rich in oils containing linoleic acid (56%) and oleic acid (25%) (Khatri et al., 2021). Additionally, they contain diverse organic compounds, including amino acids, flavonoids, glucosides, alkaloids, alcohols, esters, fatty acids, and terpenoids, particularly cucurbitacins (Ahmed et al., 2020; Khatri et al., 2021).

Although basil, bitter apple, milkweed, and thorn apple were comparatively more effective in reducing *D. citri* populations on lemons in this study, neem extracts, neem-based pesticides, and neem oil remain the most extensively evaluated agents against *D. citri*. Numerous studies have demonstrated the ability of neem-based products to induce mortality in *D. citri* adults and nymphs, along with antifeedant and repellent effects, resulting in reduced populations and damage to citrus trees (Borad et al., 2001; Khan et al., 2013, 2014; Ahmad et al., 2014; Santos et al., 2015; Zia et al., 2021).

Other plant-based products evaluated for their pesticidal potential against *D. citri* include *Artemisia* *absinthium* (Rizvi et al., 2018, 2023), guava (*Psidium guajava*) (Zaka et al., 2010; Poerwanto and Solichah, 2022), *Verbascum thapsus* (Reena et al., 2020), *D. brunonianum* (Rizvi et al., 2024), *Caulerpa sertularioides*, *Laurencia johnstonii*, and *Sargassum horridum* (González-Castro et al., 2019), *Sophora alopecuroides* (Rizvi et al., 2019), *Praxelis clematidea* (Wang et al., 2018), fir oil (Kuhns et al., 2016), *Piper aduncum* (Volpe et al., 2016), and essential oils from lavender, coriander, rose, thyme, tea tree, and rue, particularly 2-undecanone (Mann et al., 2012).

The type of extract, ethanol, methanol, or water, used in our study significantly influenced the efficacy of various plants in controlling *D. citri*. Previous studies have reported that solvents and extraction methods play a critical role in extracting active plant constituents, as well as their stability and solubility, which determine their insecticidal activity against target pests (Ahmed et al., 2019; Ahmad et al., 2021).

Sultana et al. (2009) demonstrated that aqueous ethanol and methanol solutions (containing 20% water) produced higher yields, phenolic contents, and antioxidant activity compared to absolute ethanol and methanol when evaluating *A. indica*, *Acacia nilotica*, *Eugenia jambolana*, *Terminalia arjuna*, *Moringa oleifera*, *Ficus religiosa*, and *A. barbadensis* using reflux and shaking extraction methods. Similarly, Sharma and Cannoo (2017) reported that methanol, as a solvent in Soxhlet extraction, yielded higher extraction efficiency, total phenolic content, total flavonoid content, and antioxidant potential from *Nepeta leucophylla* stems. Comparable findings were reported by Sharma and Cannoo (2016) and Iqbal et al. (2012).

Other studies have highlighted the significant impact of polar (e.g., ethyl acetate, ethanol, acetone, water) and non-polar solvents (e.g., n-hexane, petroleum ether, chloroform) on the extraction efficiency of phytochemicals for pesticidal or pharmacological applications. Combinations of polar and non-polar solvents often result in better extraction efficiency and antioxidant quality (Dirar et al., 2019; Truong et al., 2019; Nawaz et al., 2020; El Mannoubi, 2023).

Building on these findings, our study showed that ethanol and methanol extracts performed better than water extracts against *D. citri*. This enhanced efficacy may be attributed to the ability of ethanol and methanol to extract a greater number of active compounds responsible for the pesticidal activity of these plants.

CONCLUSION

All the botanical extracts tested were effective in controlling *D. citri* populations in lemon, with ethanol and methanol extracts of basil, bitter apple, and milkweed being significantly more effective than their water extracts. Therefore, it is recommended to use ethanol or methanol extracts of basil, bitter apple, or milkweed for managing *D. citri* in lemon. If ethanol or methanol extraction is not feasible, water extracts of these plants can also be used as an alternative. Moreover, further research on the chemical composition of basil, bitter apple, and milkweed is encouraged to identify the key compounds responsible for *D. citri* population reduction, which could aid in developing effective pesticide formulations.

AUTHORS' CONTRIBUTIONS

JAM conducted the experiments and collected data, IAN and MAK conceived and supervise study, ZP and FIN write the initial manuscript, JGMS and SHR help in data collection, AAG designed study, analyzed data and finalized the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Abbott, W.S., 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18(2), 265-267.

Abreu, F.A., Mendes Carvalho, L., Silva, R.A., Freire De Carvalho, C., De Nazaré, M., Ribeiro, O., Rezende, C.M., 2021. Use of basil *Ocimum basilicum* and *Chrysoperla externa* (Chrysopidae) in agroecological management of rosebushes. International Journal of Environmental and Agricultural Research 7, 7-14.

Ahmad, F., Khan, M.A., Gul, F., Suhail, A., Ullah, M., Salman, M., 2014. Evaluation of different plant extracts against citrus psylla (*Diaphorina citri* Kuwayama). Pakistan Journal of Weed Science Research 20 (3), 347-358.

Ahmad, R., Ahmad, N., Aljamea, A., Abuthayn, S., Aqeel, M., 2021. Evaluation of solvent and temperature effect on green accelerated solvent extraction (ASE) and UHPLC quantification of phenolics in fresh olive fruit (*Olea europaea*). Food Chemistry 342, 128-248.

Ahmad, S., Asim, M., Majeed, M.Z., Atiq, M., Ali, Y., Ahmad, H.B., Rehman, M.A., Akhtar, N., 2023. Population dynamics and epidemiology of *Diaphorina citri* in relation to yield losses caused by citrus greening. Punjab University Journal of Zoology 38(1), 81-88.

Ahmed, M., Ji, M., Qin, P., Gu, Z., Liu, Y., Sikandar, A., Iqbal, M.F., Javeed, A., 2019. Phytochemical screening, total phenolic and flavonoids contents and antioxidant activities of *Citrullus colocynthis* L. and *Cannabis sativa* L. Applied Ecology & Environmental Research 17(3), 6961-6979.

Ahmed, M., Peiwen, Q., Gu, Z., Liu, Y., Sikandar, A., Hussain, D., Javeed, A., Shafi, J., Iqbal, M.F., An, R., Guo, H., 2020. Insecticidal activity and biochemical composition of *Citrullus colocynthis*, *Cannabis indica* and *Artemisia argyi* extracts against cabbage aphid (*Brevicoryne brassicae* L.). Scientific Reports 10(1), 522.

Ali, A.N., Alnomani, K.A., Mubasher, M., 2022. Biological activity of *Citrullus colocynthis* L extracts on *Culex pipiens molethus* and *Musca domestica*. Journal of Biopesticides 15(2), 150-161.

Aslan, İ., Özbek, H., Çalmaşur, Ö., Şahin, F., 2004. Toxicity of essential oil vapours to two greenhouse pests, *Tetranychus urticae* Koch and *Bemisia tabaci* Genn. Industrial Crops and Products 19(2), 167-173.

Azeem, W., Mukhtar, T., Hamid, T., 2021. Evaluation of *Trichoderma harzianum* and *Azadirachta indica* in the management of *Meloidogyne incognita* in tomato. Pakistan Journal of Zoology 53(1), 119-125.

Benelli, G., Pavela, R., Maggi, F., Wandjou, J.G.N., Koné-Bamba, D., Sagratini, G., Caprioli, G., 2019. Insecticidal activity of the essential oil and polar extracts from *Ocimum gratissimum* grown in Ivory Coast: Efficacy on insect pests and vectors and impact on non-target species. Industrial Crops and Products 132, 377-385.

Bincy, K., Remesh, A.V., Prabhakar, P.R., ivek Babu, C.S., 2023. Chemical composition and insecticidal activity of *Ocimum basilicum* (Lamiaceae) essential oil and its major constituent, estragole against *Sitophilus oryzae* (Coleoptera: Curculionidae). Journal of Plant Diseases and Protection 130(3), 529-541.

Borad, P., Patel, M.J., Patel, B., Patel, M., Patel, B.H., Patel, J.R., 2001. Evaluation of some botanicals against citrus leafminer (*Phyllocnistis diretta*) and psylla (*Diaphorina citri*) on kagzilime (*Citrus aurantifolia*). Indian Journal of Agricultural Sciences 71(3), 177-179.

Bové, J.M., 2006. Huanglongbing: a destructive, newly-emerging, century-old disease of citrus. Journal of Plant Pathology 88, 7-37.

Chen, X.D., Kaur, N., Horton, D.R., Cooper, W.R., Qureshi, J.A., Stelinski, L.L., 2021b. Crude extracts and alkaloids derived from *Ipomoea-Periglandula* symbiotic association cause mortality of Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae). Insects 12(10), 929.

Chen, X.D., Neupane, S., Gill, T.A., Gossett, H., Pelz-Stelinski, K.S., Stelinski, L.L., 2021a. Comparative transcriptome analysis of thiamethoxam susceptible and resistant Asian citrus psyllid, *Diaphorina citri* (Hemiptera: Liviidae), using RNA-sequencing. Insect Science 28(6), 1708-1720.

Chowdhary, K., Kumar, A., Sharma, S., Pathak, R., Jangir, M., 2018. *Ocimum* sp.: Source of biorational pesticides. Industrial Crops and Products 122, 686-701.

Dhifi, W., Bellili, S., Jazi, S., Bahloul, N., Mnif, W., 2016. Essential oils' chemical characterization and investigation of some biological activities: A critical review. Medicines 3(4), 25.

Dirar, A.I., Alsaadi, D.H.M., Wada, M., Mohamed, M.A., Watanabe, T., Devkota, H.P., 2019. Effects of extraction solvents on total phenolic and flavonoid contents and biological activities of extracts from Sudanese medicinal plants. South African Journal of Botany 120, 261-267.

Dong, Z., Liu, X., Srivastava, A.K., Tan, Q., Low, W., Yan, X., Hu, C., 2023. Boron deficiency mediates plant-insect (*Diaphorina citri*) interaction by disturbing leaf volatile organic compounds and cell wall functions. Tree Physiology 43(4), 597-610.

El Mannoubi, I., 2023. Impact of different solvents on extraction yield, phenolic composition, *in vitro* antioxidant and antibacterial activities of deseeded *Opuntia stricta* fruit. Journal of Umm Al-Qura University for Applied Sciences 9(2), 176-184.

El-Halim, A., Hend, T., Ayad, E.L., El-Deeb, S.E., 2023. Efficiency of utilizing *Citrullus colocynthis* (L) essential oil alone and when it mixed with diatomaceous earth against some stored products insect pests. Journal of Plant Protection and Pathology 14(12), 405-413.

Gaire, S., Albrecht, U., Batuman, O., Qureshi, J., Zekri, M., Alferez, F., 2022. Individual protective covers (IPCs) to prevent Asian citrus psyllid and *Candidatus Liberibacter* asiaticus from establishing in newly planted citrus trees. Crop Protection 152, 105862.

González-Castro, A.L., Muñoz-Ochoa, M., Hernández-Carmona, G., López-Vivas, J.M., 2019. Evaluation of seaweed extracts for the control of the Asian citrus psyllid *Diaphorina citri*. Journal of Applied Phycology 31(6), 3815-3821.

Grafton-Cardwell, E.E., Stelinski, L.L., Stansly, P.A., 2013. Biology and management of Asian citrus psyllid, vector of the huanglongbing pathogens. Annual Review of Entomology 58, 413-432.

Hall, D.G., Richardson, M.L., Ammar, E.D., Halbert, S.E., 2013. Asian citrus psyllid, *Diaphorina citri*, vector of citrus huanglongbing disease. Entomologia Experimentalis et Applicata 146(2), 207-223.

Hassam, U.A., Gulzar, A., Rasool, B., Zafar, S., Younis, T., Shakeel, M., Hafeez, M., 2022. Efficacy of *Citrullus colocynthis* seed extract on *Earias vittella*, Fabricius, (Lepidoptera: Noctuidae): environment sustainable approach. Brazilian Journal of Biology 84, e254479.

Iqbal, S., Younas, U., Chan, K.W., Zia-Ul-Haq, M., Ismail, M., 2012. Chemical composition of *Artemisia annua* L. leaves and antioxidant potential of extracts as a function of extraction solvents. Molecules 17(5), 6020-6032.

Jabbar, A., Tariq, M., Gulzar, A., Mukhtar, T., Zainab, T., 2022. Lethal and sub lethal effects of plant extracts and green silver nanoparticles against *Culex pipiens* mosquitoes. Pakistan Journal of Zoology 54(3), 1259-1267.

Kamaraj, C., Deepak, P., Balasubramani, G., Karthi, S., Arul, D., Aiswarya, D., Perumal, P., 2018. Target and non-target toxicity of fern extracts against mosquito vectors and beneficial aquatic organisms. Ecotoxicology and Environmental Safety 161, 221-230.

Kayani, M.Z., Mukhtar, T., Hussain, M.A., 2012. Evaluation of nematicidal effects of *Cannabis sativa* L. and *Zanthoxylum alatum* Roxb. against root-knot nematodes, *Meloidogyne incognita*. Crop Protection 39, 52-56.

Kéita, S.M., Vincent, C., Schmit, J.P., Arnason, J.T., Bélanger, A., 2001. Efficacy of essential oil of *Ocimum basilicum* L. and *O. gratissimum* L. applied as an insecticidal fumigant and powder to control *Callosobruchus maculatus* (Fab.) [Coleoptera: Bruchidae]. Journal of Stored Products Research 37(4), 339-349.

Khan, A.A., Afzal, M., Qureshi, J.A., Khan, A.M., Raza, A.M., 2014. Botanicals, selective insecticides, and predators to control *Diaphorina citri* (Hemiptera: Liviidae) in citrus orchards. Insect Science 21(6), 717-726.

Khan, A.A., Afzal, M., Raza, A.M., Khan, A.M., Iqbal, J., Tahir, H.M., Aqeel, M.A., 2013. Toxicity of botanicals and selective insecticides to Asian citrus psylla, *Diaphorina citri* K. (Homoptera: Psyllidae) in laboratory conditions. Jokull Journal 63(8), 52-72.

Khan, H.S., Tariq, M., Mukhtar, T., Gulzar, A., 2021. Insecticidal toxicity of plant extracts and green silver nanoparticles against *Aedes albopictus*. Pakistan Journal of Zoology 53(6), 2123-2128.

Khatri, S., Faizi, S., Fayyaz, S., Iqbal, E., 2021. *Citrullus colocynthis*: A treasure of phytochemical, pharmacological, pesticidal and nematicidal compounds. Pakistan Journal of Nematology 39(2), 122-150.

Kuhns, E.H., Martini, X., Hoyte, A., Stelinski, L.L., 2016. Repellent activity of botanical oils against Asian citrus psyllid, *Diaphorina citri* (Hemiptera: Liviidae). Insects 7(3), 35.

Kunbhar, S., Rajput, L.B., Gilal, A.A., Channa, G.A., Sahito, J.G.M., 2018. Impact of botanical pesticides against sucking insect pests and their insect predators in brinjal crop. Journal of Entomology and Zoology Studies 6(2), 83-87.

Larbi, B., Ali, B., M'hammed, A.M., 2021. Evaluating the biocontrol potential of insects auxiliary and bio-insecticide extracted from *Citrullus colocynthis* against *Parlatoria blanchardi* in date palm in Saoura Oases, Algeria. South Asian Journal of Experimental Biology 11(4), 369-377.

Lee, X., Wong, C., Coats, J., Paskewitz, S., 2022. Semi-field evaluations of three botanically derived repellents against the blacklegged tick, *Ixodes scapularis* (Acari: Ixodidae). bioRxiv 2022-01.

Liang, Z.L., Liang, M.W., Deng, T.J., Liu, J.M., Liu, L.H., 2023. Outbreak causes and control strategies of the *Diaphorina citri* and its relation with citrus Huanglongbing. Plant Quarantine 37(3), 26-30.

Mann, R.S., Ali, J.G., Hermann, S.L., Tiwari, S., Pelz-Stelinski, K.S., Alborn, H.T., Stelinski, L.L., 2012. Induced release of a plant-defense volatile 'deceptively' attracts insect vectors to plants infected with a bacterial pathogen. PLoS Pathogens 8(3), e1002610.

Martinez-Velazquez, M., Castillo-Herrera, G.A., Rosario-Cruz, R., Flores-Fernandez, J.M., Lopez-Ramirez, J., Hernandez-Gutierrez, R., del Carmen Lugo-Cervantes, E., 2011. Acaricidal effect and chemical composition of essential oils extracted from *Cuminum cyminum*, *Pimenta dioica* and *Ocimum basilicum* against the cattle tick *Rhipicephalus* (*Boophilus*) *microplus* (Acari: Ixodidae). Parasitology Research 108, 481-487.

Maurya, P., Sharma, P., Mohan, L., Verma, M.M., Srivastava, C.N., 2012. Larvicidal efficacy of *Ocimum basilicum* extracts and its synergistic effect with neonicotinoid in the management of *Anopheles stephensi*. Asian Pacific Journal of Tropical Disease 2(2), 110-116.

Moura, E.D.S., Faroni, L.R.D.A., Heleno, F.F., Rodrigues, A.A.Z., 2021. Toxicological stability of *Ocimu basilicum* essential oil and its major components in the control of *Sitophilus zeamais*. Molecules 26(21), 6483.

Mukhtar, T., Kayani, M.Z., Hussain, M.A., 2013. Nematicidal activities of *Cannabis sativa* L. and *Zanthoxylum alatum* Roxb. against *Meloidogyne incognita*. Industrial Crops and Products 42, 447-453.

Naeem, A., Freed, S., Jin, F.L., Akmal, M., Mehmood, M., 2016. Monitoring of insecticide resistance in *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae) from citrus groves of Punjab, Pakistan. Crop Protection 86, 62-68.

Naveen, M., Jayaraj, J., Chinniah, C., Mini, M.L., Vellaikumar, S., Shanthi, M., 2021. Insecticidal property of methanolic leaf extract of sweet basil, *Ocimum basilicum* (L.) against cigarette beetle, *Lasioderma serricorne* (Fab.)(Coleoptera: Anobiidae). Journal of Entomology and Zoology Studies 9(1), 259-262.

Nawaz, H., Shad, M.A., Rehman, N., Andaleeb, H., Ullah, N., 2020. Effect of solvent polarity on extraction yield and antioxidant properties of phytochemicals from bean (*Phaseolus vulgaris*) seeds. Brazilian Journal of Pharmaceutical Sciences 56, e17129.

Ogbebor, N.O., Adekunle, A.T., Enobakhare, D.A., 2007. Inhibition of *Colletotrichum gloeosporioides* (Penz) Sac. causal organism of rubber (*Hevea brasiliensis* Muell. Arg.) leaf spot using plant extracts. African Journal of Biotechnology 6(3), 213-218.

Ouko, R.O., Koech, S.C., Arika, W.M., Njagi, S.M., Oduor, R.O., Ngugi, M.P., 2017. Bioefficacy of organic extracts of *Ocimum basilicum* against *Sitophilus zeamais*. Entomology, Ornithology, & Herpetology 6(190), 2161-0983.

Pardo-Melgarejo, S., Rodríguez-Maciel, J.C., Pineda, S., Lagunes-Tejeda, Á., Guzmán-Franco, A.W., Silva-Aguayo, G., Ramírez-Sánchez, A.K., 2023. Thirty-minute test to detect insecticide resistance under field conditions: the case of the Asian citrus psyllid. Pest Management Science 79(9), 3159-3166.

Poerwanto, M.E., Solichah, C., 2022, April. Potency of guava shoot extract as a control means against *Diaphorina citri*. Proceedings of IOP Conference Series: Earth and Environmental Science 1018(1), 012045. IOP Publishing.

Reena, Singh, V.B., Sinha, B.K., Singh, A.P., Kumar, R., Singh, P., 2020. Evaluation of some botanicals against citrus psylla *Diaphorina citrii*. Indian Journal of Entomology 82(2), 265-267.

Rizvi, S.A.H., Al-Shuraym, L.A., Al-Ghamdi, M.S., Al Galil, F.M.A., Al-Mekhlafi, F.A., Wadaan, M., Jaleel, W., 2023. Evaluation of *Artemisia absinthium* L. essential oil as a potential novel prophylactic against the Asian citrus psyllid *Diaphorina citri* Kuwayama. Horticulturae 9(7), 758.

Rizvi, S.A.H., Ling, S., Tian, F., Xie, F., Zeng, X., 2018. Toxicity and enzyme inhibition activities of the essential oil and dominant constituents derived from *Artemisia absinthium* L. against adult Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae). Industrial Crops and Products 121, 468-475.

Rizvi, S.A.H., Liu, Z., Ozuzu, S.A., Arafat, Y., Han, C., Maggi, F., Shao, H., 2024. Toxicity of *Delphinium brunonianum* Royle alkaloids against the adults of *Diaphorina citri* and its mechanism study in insect SF9 cell line. Industrial Crops and Products 208, 117826.

Rizvi, S.A.H., Xie, F., Ling, S., Zeng, X., 2019. Development and evaluation of emulsifiable concentrate formulation containing *Sophora alopecuroides* L. extract for the novel management of Asian citrus psyllid. Environmental Science and Pollution Research 26, 21871-21881.

Rodríguez-González, Á., Álvarez-García, S., González-López, Ó., Da Silva, F., Casquero, P.A., 2019. Insecticidal properties of *Ocimum basilicum* and *Cymbopogon winterianus* against *Acanthoscelides obtectus*, insect pest of the common bean (*Phaseolus vulgaris*, L.). Insects 10(5), 151.

Rohim, A.N., Poerwanto, M.E., Solichah, C., Holford, P., 2023. Repellency of lemongrass extract (*Cymbopogon nardus*) in solid and liquid formulation on *Diaphorina citri* and *Menochilus sexmaculatus*. Proceedings of BIO Web of Conferences 69, 01030). EDP Sciences.

Sa'adah, N.S.S., Sukirno, S., Alwandri, H., Nuringtyas, T.R., Nugroho, L.H., 2023. A bibliometric analysis of botanical insecticides for Lepidopteran insects over the period 1985-2022. Plant Science Today 10(1), 232-241.

Saeed, M., Mukhtar, T., Haq, M.I., Khan, M.A., 2021. Assessment of nematicidal potential of *Cannabis sativa* and *Azadirachta indica* in the management of root-knot nematode (*Meloidogyne javanica*) on peach. Pakistan Journal of Agricultural Sciences 58(5), 1555-1561.

Santos, M.S., Zanardi, O.Z., Pauli, K.S., Forim, M.R., Yamamoto, P.T., Vendramim, J.D., 2015. Toxicity of an azadirachtin-based biopesticide on *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) and its ectoparasitoid *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae). Crop Protection 74, 116-123.

Sharma, A., Cannoo, D.S., 2016. Comparative evaluation of extraction solvents/techniques for antioxidant potential and phytochemical composition from roots of *Nepeta leucophylla* and quantification of polyphenolic constituents by RP-HPLC-DAD. Journal of Food Measurement and Characterization 10, 658-669.

Sharma, A., Cannoo, D.S., 2017. A comparative study of effects of extraction solvents/techniques on percentage yield, polyhenolic composition, and antioxidant potential of various extracts obtained from stems of *Nepeta leucophylla*: RP-HPLC-DAD assessment of its polyhenolic constituents. Journal of Food Biochemistry 41(2), e12337.

Silva, S.M., Cunha, J.P.A.R.D., Carvalho, S.M.D., Zandonadi, C.H.S., Martins, R.C., Chang, R., 2017. *Ocimum basilicum* essential oil combined with deltamethrin to improve the management of *Spodoptera frugiperda*. Ciência e Agrotecnologia 41, 665-675.

Singerman, A., Rogers, M.E., 2020. The economic challenges of dealing with citrus greening: The case of Florida. Journal of Integrated Pest Management 11(1), 3.

Sultana, B., Anwar, F., Ashraf, M., 2009. Effect of extraction solvent/technique on the antioxidant activity of selected medicinal plant extracts. Molecules 14(6), 2167-2180.

Tang, T., Zhao, M., Wang, P., Huang, S., Fu, W., 2021. Control efficacy and joint toxicity of thiamethoxam mixed with Spirotetramat against the Asian citrus psyllid, *Diaphorina citri* Kuwayama. Pest Management Science 77(1), 168-176.

Tayyab, M.B., Majeed, M.Z., Riaz, M.A., Aqueel, M.A., Ouedraogo, S.N., Luqman, M., Tanvir, M., 2022. Insecticidal potential of indigenous flora of Soon valley against Asian citrus psyllid *Diaphorina citri* kuwayama and cotton aphid *Aphis gossypii* glover. Sarhad Journal of Agriculture 38, 26-39.

Tennyson, S., Ravindran, K.J., Arivoli, S., 2012. Screening of twenty five plant extracts for larvicidal activity against *Culex quinquefasciatus* Say (Diptera: Culicidae). Asian Pacific Journal of Tropical Biomedicine 2(2), S1130-S1134.

Tian, F., Rizvi, S.A.H., Liu, J., Zeng, X., 2020. Differences in susceptibility to insecticides among color morphs of the Asian citrus psyllid. Pesticide Biochemistry and Physiology 163, 193-199.

Truong, D.H., Nguyen, D.H., Ta, N.T.A., Bui, A.V., Do, T.H., Nguyen, H.C., 2019. Evaluation of the use of different solvents for phytochemical constituents, antioxidants, and *in vitro* anti-inflammatory activities of *Severinia buxifolia*. Journal of Food Quality. Article ID8178294. https://doi.org/10.1155/2019/8178294

Volpe, H.X., Fazolin, M., Garcia, R.B., Magnani, R.F., Barbosa, J.C., Miranda, M.P., 2016. Efficacy of essential oil of *Piper aduncum* against nymphs and adults of *Diaphorina citri*. Pest Management Science 72(6), 1242-1249.

Wang, Q.Z., Liu, Y.M., Li, S.M., Zhao, Y., Wang, W., 2018. Chemical composition of essential oil of the invasive plant *Praxelis clematidea* and its repellence and lethality to *Diaphorina citri*. Chinese Journal of Applied Entomology 55(1), 117-125.

Yuan, C.Y., Jing, T.X., Li, W., Liu, X.Q., Liu, T.Y., Liu, Y., Chen, M.L., Jiang, R.X., Yuan, G.R., Dou, W., Wang, J.J., 2021. NADPH-cytochrome P450 reductase mediates the susceptibility of Asian citrus psyllid *Diaphorina citri* to imidacloprid and thiamethoxam. Pest Management Science 77(2), 677-685.

Zaka, S.M., Zeng, X.N., Holford, P., Beattie, G.A.C., 2010. Repellent effect of guava leaf volatiles on settlement of adults of citrus psylla, *Diaphorina citri* Kuwayama, on citrus. Insect Science 17(1), 39-45.

Zia, A.S., Shakur, M., Hussain, R., Amin, M., Ullah, K., Ahmad, S., Ahmad, S., Shayan, M., Ali, A., Shah, M.K., Iftikhar, H., Amanullah., 2021. Efficacy of various synthetic and botanical insecticides against citrus psylla (*Diaphorina citri* Kuwayama) (Homoptera: Psyllidae) in citrus. NVEO-Natural Volatiles & Essential Oils Journal 8(1), 123-129.