



The toxicity, repellent, and biochemical effects of four wild plant extracts against *Aphis gossypii* Glover and *Phenacoccus solenopsis* Tinsley: HPLC analysis of phenolic compounds

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Abstract The insecticidal and repellent activities of the four wild plant extracts: stinging nettle, *Urtica dioica* L., white henbane, *Hyoscyamus albus* L., camphorweeds, *Pluchea dioscoridis* L., and cocklebur, *Xanthium strumarium* L. were tested compared to the insecticide spirotetramat against the 3rd nymphal instar of *Aphis gossypii* Glover and adult females of *Phenacoccus solenopsis* Tinsley after 24 and 48 h of treatment. Their effects on acetylcholinesterase (AChE) and glutathione-S-transferase (GST) enzyme activities were also assessed to explore their possible mechanisms of action. The phenolic compounds of the plant extracts were investigated by high-performance liquid chromatography (HPLC) analysis. The most abundant compounds in the methanol extract from *P. dioscoridis* were gallic acid (14.45 µg/mL),

and cinnamic acid (11.44 µg/mL); from *U. dioica* were caffeic acid (15.32 µg/mL) and syringic acid (13.47 µg/mL); from *H. albus* were syringic acid (7.12 µg/mL) and catechol (5.33 µg/mL); and from *X. strumarium* were *p*-coumaric acid (24.53 µg/mL) and pyrogallol (18.35 µg/mL). According to the LC₅₀ values, the contact toxicity of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* against *A. gossypii* was 40.3, 60.6, 56.2, and 32.3 mg/L, whereas, the contact toxicity against *P. solenopsis* was 56.4, 67.5, 64.3, and 36.2 mg/L, compared to the spirotetramat (17.2 and 24.5 mg/L), respectively, at 48 h of treatment. The highest repellency rates were observed with LC₅₀ values for *X. strumarium* (63.2 and 60.3%), followed by *U. dioica* (46.2 and 43.5%), *P. dioscoridis* (45.3 and 42.8%), and *H. albus* extract (38.8 and 35.2%) compared to the spirotetramat (78.5 and 76.2%) against *A. gossypii* and *P. solenopsis* at 24 h, but decreased with time. The AChE and GST activities in pests were significantly inhibited, compared to control and spirotetramat, with dose and time-dependent effects. These findings indicate that tested wild extracts may be suggested as viable alternatives for aphids and mealybugs control.

Keywords Aphids · Mealybugs · Cotton crop · Botanical insecticide · HPLC · Contact toxicity · Repellency · Acetylcholinesterase · Glutathione-S-transferase

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Introduction

The melon/cotton aphids, *Aphis gossypii* Glover (Hemiptera: Aphididae), and the cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), are among the most serious piercing-sucking insect pests of economically important agricultural and horticultural crops worldwide (Shera et al., 2010; Hullé et al., 2020; Waqas et al., 2021; Zha et al., 2024). These pests are highly polyphagous, cause economic damage by feeding on the plant phloem tissues, producing sooty mold as a result of excreting honeydew, and ultimately hindering the photosynthetic activity in plants (Emden & Harrington, 2017; Subramanian et al., 2021). Aphids can also transmit numerous plant pathogenic viruses, such as cucumber mosaic virus (CMV), zucchini yellow mosaic virus (ZYMV) and cotton leafroll dwarf virus (Webb, 2017; Heilsnis et al., 2023). Mealybugs are less effective in transmitting plant viruses than aphids, due to their less mobile nature; they transmit viruses of the genus like Ampeloviruses and Badnaviruses (Ahmed et al., 2023). In Egypt, *P. solenopsis* was recorded for the first time as an invasive pest on weed plants (Abdel-Razzik et al., 2015).

Regrettably, cotton cultivation is frequently plagued by various pests including aphids and mealybugs, which not only threaten the yield and quality of the crop but also potentially suffer economic losses for farmers, making the use of insecticides to control these pests inevitable (Khan et al., 2020). Accordingly, there is a pressing need to identify efficient and eco-friendly alternatives to avoid excessive consumption of these chemicals, therefore delaying the emergence of resistance and limiting adverse effects on the environment (Hussein et al., 2022). Therefore, botanical insecticides have been submitted as an effective way to manage insect pests and seem to be safer for the environment and human health when compared to synthetic insecticides (Campos et al., 2019; Tawfeek et al., 2021; De Melo et al., 2023; Meenakshi et al., 2023; Ahmed & Abdelwines, 2024; Awad et al., 2024). Besides, they affect only the target insects with little or no detrimental effects on beneficial insects like pollinators and natural enemies (Isman, 2020; Moustafa et al., 2021). Consequentially, in the present work, four wild-growing plants in Alexandria, Egypt, were used as sources of natural extracts for managing

and controlling the growth of *Aphis gossypii* Glover and *Phenacoccus solenopsis* Tinsley.

Stinging nettle (*Urtica dioica* L.) is one of the perennial wild plants belonging to the family Urticaceae, which is widespread in temperate regions in many parts of North Africa, Asia, Europe, and North America (Đurović et al., 2024). Chemical analysis of nettle showed the presence of bioactive compounds such as terpenes, carotenoids, chlorophyll, fatty acids, vitamins, minerals, polyphenolic compounds, amino acids, and pigments (Repajić et al., 2021; Behiry et al., 2022). Several extracts from this plant had observed promising insecticidal activity against bruchins (González-Macedo et al., 2021), the domestic mosquito *Culex pipiens* and phlebotomine sand fly *Phlebotomus papatasi* (Randa et al., 2024), and on the third larval instars of *Tribolium confusum* (Rasheed & Al-Sinjari, 2022).

White henbane (*Hyoscyamus albus* L.) is a Mediterranean plant that belongs to the Solanaceae family and has a remarkable composition that includes polyphenolic compounds (flavonoids, and tannins) as well as terpenoids and alkaloids (Mobin et al., 2015). Several compounds have been isolated from this plant, including grivilloside H, betulaplatoiside, scopamine, β -sitosterol, and stigmaterol (Ashraf et al., 2019). Alkaloid compounds including 2, 3-dimethylnonacosane, scopolamine, atropine, hyoscyne, and hyoscyamine were isolated from the aerial parts of *H. albus* (Mahmood et al., 1985).

Pluchea dioscoridis (L.), or *Conyza dioscoridis* (L.), belongs to the Asteraceae family. It is referred to as a mosquito tree because of its repellent effect on mosquitoes (Shaltout & Slima, 2007). These may be associated with the bioactive substances found in the essential oil extracted from the aerial portions, such as cadinene, berkheyeradulene, δ -cadinene, *trans*-Z- α -bisabolene oxide, 5-epi-shyobunol, carophyllene, α -guaiene, and α -cadinol (Elshamy et al., 2015). Additionally, to a few additional molecules including rhamanetin, epicatechi, isorhamnetin 3-sulfate, isorhamnetin 3-O-rutinoside, methyl 15-oxo-eudesone-4, 11(13)-diene 12-oate, and 1 α ,9 α -dihydroxy- α -cyclocostunolide (Balah, 2016). El-Seedi et al. (2017) reported that the essential oil of *C. dioscoridis* had a repellent effect against the nymphs of *Ixodes ricinus* of 94% at 1 mg/mL concentration after 5 min of application, and of 61.1% at 6.5 μ g/cm² concentration when applied

in a field conditions. From a phytochemical view, *P. dioscoridis* produces diverse bioactive secondary metabolites; including triterpenes, steroids, phenolic acids, and flavonoids. Prior investigation on this plant revealed its larvicidal efficacy against *Culex pipiens*, the main vector of lymphatic filariasis in Egypt (Madboly et al., 2023).

For the insecticidal activity of the extracts, the aerial component of *C. dioscoridis* is a promising botanical pesticide that targets *S. littoralis* larvae in their fourth instar through a variety of mechanisms of action (Matloub et al., 2021), and the against the cotton pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) (Yousef, 2015). β -Amyrin-3-acetate, β -lupeol-3-acetate, and β -amyrenone along with dotriacontane hydrocarbon as well as one methoxyflavone; 5,4'-dihydroxy-6,7-dimethoxyflavone were identified in *C. dioscoridis* extract (Matloub et al., 2021).

Cocklebur (*Xanthium strumarium* L.) is an annual herb belonging to the family Asteraceae. Researchers have shown that *X. strumarium* is effective as a fungicide, acaricide, and insecticide and has antifeeding and repellent properties (Sahoo et al., 2020). The extract was observed bioactivity against adult tea mosquito bug, *Helopeltis theivora* (Sarmah & Bhola, 2014), *Culex mosquitoes* (Diptera: Culicidae) (Roba et al., 2015), on the green peach aphid [*Myzus persicae* Sulzer] (Hemiptera: Aphididae) (Erdoğan & Yıldırım, 2016), and on colorado potato beetle *Leptinotrasa decemlineata* Say (Col: Chrysomelidae) (Çetinsöy et al., 1998).

Spirotetramat, a derivative of tetramic acid, acts as a lipid biosynthesis inhibitor, which lowers the fecundity and fertility of sap-sucking insects. Some studies have shown that spirotetramat is less toxic to honeybees and other beneficial invertebrates (Nauen et al., 2008). AChE and GST generally have key functions in the interaction between insects and host plants or chemical pesticides. Studies on enzyme inhibition significantly enhance the current understanding of enzyme specificity and the mechanisms by which enzymes and toxic agents work (Zhou et al., 2016).

Therefore, this study aimed to identify the phenolic compounds and determine the toxic and repellent effects of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* extracts against *A. gossypii* and *P. solenopsis*, as well as their effects on the activities of two important enzymes (AChE and GST) to explore the

possible insecticidal potential and underlying mechanism of the extracts in the future.

Materials and methods

Insect rearing

The colonies of *A. gossypii* and *P. solenopsis* were originally collected from the infested cotton fields (*Gossypium barbadense* Linnaeus, Malvaceae) in Abees district, Alexandria, Egypt. Insect culture was reared for 3–4 generations on cotton seedlings planted in plastic pots in a greenhouse at a temperature of $25 \pm 2^\circ\text{C}$ and relative humidity of $65 \pm 5\%$ under natural lighting without exposure to insecticides (Tawfeek & Eldesouky, 2022; Eldesouky et al., 2023). *A. gossypii* and *P. solenopsis* were identified based on taxonomic keys and morphological characters at the Department of Applied Entomology and Zoology, Faculty of Agriculture, Alexandria University, Egypt.

Plant materials and extraction

Four weed species, stinging nettle, *Urtica dioica* L., white henbane, *Hyoscyamus albus* L., camphorweeds, *Pluchea dioscoridis* L., and cocklebur, *Xanthium strumarium* L., were collected from Alexandria, Egypt, in 2020. The identification of plant materials was carried out by botanists at Alexandria University and vouchered under the numbers of SA012, SA013, SA014, and SA015, respectively. Plant extracts were prepared by the maceration method. The aerial parts were air-dried at room temperature for approximately 10 days with, then then ground with an electric blender and sieved to get fine powder. The 50 g of each dried and powdered part was weighed and soaked in 200 mL of methanol (98%; manufactured by PIOCHEM®), separately in a stoppered conical flask (500 mL) for a definite period of 7 days. The extraction process was repeated three times in the week under shaking for 5 min at 250 rpm, where every filtration was done after two days. Afterthought, all extracts were filtered through filter paper (Whatman No. 1), and the combined extract from each plant part was concentrated by evaporating the methanol solvent using a rotary-evaporator at 45°C . The plant extracts were stored in a refrigerator at 4°C in airtight glass vials.

HPLC analysis of phenolic compounds

The phenolic compound from the methanol extracts of *U. dioica*, *H. albus*, *P. dioscoridis* and *X. strumarium* aerial parts were analyzed using HPLC (Agilent 1100, Agilent ChemStation) had a UV/Vis detector, two LC pumps, and a C18 column (125 mm × 4.6 mm, 5 µm particle size) was used to gather and examine chromatograms. By using a gradient mobile phase of two solvents—Solvent A (Methanol) and Solvent B [Acetic acid in water (1:25)]. For the first 3 min, the gradient program was maintained at a concentration of 100% B. The concentration of eluent A was then raised to 80% for the following 2 min, then decreased to 50% once again for the following 5 min detection wavelength at 250 nm. This was followed by 5 min of 50% eluent A. As a result, the order of phenolic compounds was established utilizing this mobile phase to verify standard compounds (Hassan et al., 2021; El-Hefny et al., 2023; Alkharpotly et al., 2024). All solvents and reagents used in experiments were analytical grade.

Bioassays

The contact toxicity of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* plant extracts compared to the insecticide, spirotetramat against the 3rd nymphal instar of *A. gossypii* Glover and adult females of *P. solenopsis* Tinsley were tested using the standard leaf-dipping methods. A preliminary test was run to determine the appropriate testing concentrations. Spirotetramat (Movento® 10% SC), was purchased from Bayer Crop Science, Germany and used as a positive control. Concentrations (10–100 mg/L) of each plant extract were prepared by dissolving in distilled water with 0.05% Triton X-100 and 0.1% dimethyl sulfoxide (DMSO) as an emulsifier. Cotton leaf discs of 5 cm diameter were cut from unsprayed cotton leaves and immersed in each concentration for 20 s. There were two controls: one that was sprayed with distilled water, and the other that contained 0.1% DMSO and 0.05% Triton X-100 only. Both treated and control leaf discs were air-dried and placed into a Petri dish (9 cm in diameter) containing filter paper. Then, twenty of the 3rd nymphal instar of aphids and adult females of mealybugs were placed in each dish, and identified using a stereoscopic microscope. Females of *P. solenopsis* are non-winged, less motile and voracious feeders by comparison with

winged, motile and non-feeding adult males (Waqas et al., 2021). Each treatment was replicated five times and the mortality percentage was recorded after 24 and 48 h of treatment.

Repellent test

The repellency of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* plant extracts compared to the insecticide spirotetramat against the 3rd nymphal instar of *A. gossypii* Glover and adult females of *P. solenopsis* Tinsley was evaluated (Liu et al., 2013). Filter papers (9 cm in diameter) were cut into two halves, where one half was immersed in distilled water with 0.05% Triton X-100 and 0.1% DMSO (control). In contrast, the other was immersed for 20 s in one of the three concentrations (LC₁₀, LC₂₅ and LC₅₀) of each plant extract or the insecticide, which estimated from the contact toxicity assay. These were chosen in accordance with many researchers, where they evaluated the effect of lethal and sublethal concentrations against aphids and cotton mealybugs (Gul et al., 2023; Azar et al., 2024; Hussain et al., 2024).

Insect pests are subjected to reduced doses and concentrations, resulting in many sublethal effects, including physiological and behavioral alterations, while the application of lethal concentrations can cause rapid mortality in the target pests. Both treated and control papers were joined together with the scotch tape and put into the Petri dishes (9 cm in diameter) after air drying. Twenty 3rd nymphal instar and adult females of aphids and mealybugs, respectively, were placed in the center of each Petri dish. Five replicates were made in each treatment. The number of insects present in the control area (C) and treated area (T) was recorded after 24 and 48 h of treatment. The percent of repellency of the tested compounds was calculated by using the following formula: RP (%) = [(Nc – Nt)/(Nc + Nt)] × 100; Where Nc was the number of insects present in the control half, Nt was the number of insects presents in the treated half.

Determination of detoxification enzyme activities

Sample preparation

The 3rd nymphal instar and adult females of aphids and mealybugs were treated with the LC₁₀, LC₂₅ and

LC₅₀ values of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* extracts compared to the insecticide spirotetramat. After 24 and 48 h of treatment, the treated and untreated nymphs or adult females (2 g) were homogenized in 20 ml of 0.1 M ice-cold phosphate buffer (pH 7.4) using a Polytron Kinemetica. The homogenates were centrifuged at 12,000 rpm for 30 min at 4 °C using Cryofuge 20–3, Heraeus Christ centrifuge. The clear supernatants were stored at -20 °C to measure enzyme activity and protein content. For each enzyme assay, three replicates per treatment were used. The protein content was measured by using bovine serum albumin (BSA) as a standard (Lowry et al., 1951).

Acetylcholinesterase (AChE) activity assay

The AChE activity was estimated by the colorimetric method (Ellman et al., 1961) using acetylthiocholine iodide (ATChI) as substrate. Enzyme aliquots (50 µL) and dithiodinitrobenzoic (DTNB) (100 µl of 0.01 M) were added to 0.1 M phosphate buffer (pH 8.0; 2.8 mL). To this mixture, 20 µL of each compound solution prepared in acetone and Triton-X 100 (at concentration of 0.01%) was added. Acetone (20 µL) was added in control treatments. The reaction was allowed to start by adding ATChI (30 µL of 15 mM) followed by incubation at 37 °C for 10 min. The change in absorption at 412 nm was monitored on Sequoia-Turner Model 340 spectrophotometer. The specific activity was expressed as µmol acetylthiocholine hydrolyzed/min/mg protein.

Glutathione-S-transferase (GST) activity assay

The GST activity was estimated by using 1-chloro-2, 4-dinitrobenzene (CDNB), and reduced glutathione (GSH) as substrates (Habig et al., 1974). The experimental setup involved a reaction solution including 100 µL of enzyme solution, 10 µL of 30 mM CDNB, and 10 µL of 50 mM GSH. This solution was subjected to measurement at 340 nm using a V-530 UV/Vis spectrophotometer, with the temperature maintained at 25 °C. The measurement duration was set to 3 min. The enzyme activity was determined using a molar absorptivity of 9.6 mM cm⁻¹ for CDNB. The specific activity was expressed as µmol CDNB produced/min/mg protein.

Statistical analysis

The LC₁₀, LC₂₅, LC₅₀, and LC₉₀ values along with their corresponding 95% confidence limits were calculated using the Probit analysis (Finney, 1971). One-way analysis of variance (ANOVA) was used to compare the differences between the means of the treatments with Tukey's honest significant difference (HSD) test, as $P < 0.05$ was considered significant using CoStat Version 3 (Cohort Software Inc., 1985).

Results

Phenolic compounds by HPLC

Table 1; Fig. 1 show the phenolic compounds in the methanol extracts from *P. dioscoridis*, *U. dioica*, *H. albus*, and *X. strumarium* aerial parts. The most abundant compounds in *P. dioscoridis* methanol extract were gallic acid (14.45 µg/mL), cinnamic acid (11.44 µg/mL), and ferulic acid (6.14 µg/mL). In the methanol extract from *U. dioica*, the main phenolic compounds were caffeic acid (15.32 µg/mL) and syringic acid (13.47 µg/mL). The most concentrated phenolic compounds identified in the methanol extract from *H. albus* were syringic acid (7.12 µg/mL) and catechol (5.33 µg/mL). In the methanol extract from *X. strumarium*, the abundant phenolic compounds were *p*-coumaric acid (24.53 µg/mL) and pyrogallol (18.35 µg/mL).

Contact toxicity of the plant extracts against *A. gossypii*

Firstly, the mortality percentages of the 3rd nymphal instar of *A. gossypii* were recorded, and the LC₅₀ values were calculated according to Finney (1971), as shown in Tables 2 and 3. The contact toxicity of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* against the 3rd nymphal instar of *A. gossypii* at 24 h of treatment was 62.5, 86.8, 78.9, and 45.4 mg/L, respectively, compared to the spirotetramat (21.2 mg/L), whereas, the contact toxicity was 40.3, 60.6, 56.2, and 32.3 mg/L, respectively, compared to spirotetramat (17.2 mg/L), at 48 h of treatment (Table 3).

Table 1 Phenolic compounds of the methanol extracts from *P. dioscoridis*, *U. dioica*, *H. albus* and *X. strumarium* aerial parts

Compound	Concentration (µg/mL)			
	<i>P. dioscoridis</i>	<i>U. dioica</i>	<i>H. albus</i>	<i>X. strumarium</i>
Chlorogenic acid	2.65	ND	ND	ND
Catechol	ND	ND	5.33	ND
Syringic acid	2.88	13.47	7.12	ND
<i>p</i> -Coumaric acid	3.14	ND	ND	24.53
Cinnamic acid	11.44	2.02	2.19	ND
Vanillin	ND	ND	ND	5.68
Caffeic acid	3.03	15.32	1.98	6.77
Pyrogallol	1.56	ND	ND	18.35
Gallic acid	14.45	1.23	2.09	ND
Ferulic acid	6.14	ND	ND	ND
Ellagic acid	ND	3.54	ND	ND

ND: Not detected

Contact toxicity of the plant extracts against *P. solenopsis*

Likewise, the mortality percentages of the adult females of *P. solenopsis* were recorded and the LC₅₀ values were calculated, as shown in Tables 4 and 5. The contact toxicity of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* extracts against the adult females of *P. solenopsis* at 24 h of treatment was 76.2, 90.8, 88.3, and 52.0 mg/L, compared to the spirotetramat (28.4 mg/L), while, the contact toxicity was 56.4, 67.5, 64.3, and 36.2 mg/L, respectively, compared to the spirotetramat (24.5 mg/L), at 48 h of treatment (Table 5).

Repellent effect of the plant extracts on *A. gossypii* and *P. solenopsis*

The repellent effect of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* extracts with the three concentrations (LC₁₀, LC₂₅, and LC₅₀) compared to the insecticide spirotetramat on *A. gossypii* and *P. solenopsis* was evaluated at 24 and 48 h after treatment (Table 4). The results indicated that the repellency rates increased with increased concentrations but decreased with time. The maximum repellency percentages were observed at 24 h with LC₅₀ values for *X. strumarium* (63.2 and 60.3%), followed by *U. dioica* (46.2 and 43.5%), *P. dioscoridis* (45.3 and 42.8%), and *H. albus* extract (38.8 and 35.2%)

compared to the spirotetramat (78.5 and 76.2%), against *A. gossypii* and *P. solenopsis* (Table 6).

Effect of plant extracts on AChE activities in *A. gossypii* and *P. solenopsis*

The activity of AChE in *A. gossypii* and *P. solenopsis* treated with LC₁₀, LC₂₅, and LC₅₀ concentrations of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* extracts was assessed at 24 and 48 h after treatment (Figs. 2 and 3). The results showed that the AChE activities in *A. gossypii* at 24 h ($F=15.78$; $p<0.001$) and 48 h ($F=13.46$; $p<0.001$) and in *P. solenopsis* adults at 24 h ($F=9.82$; $p<0.001$) and 48 h ($F=8.65$; $p<0.001$), were significantly inhibited compared to the control and spirotetramat.

Effect of plant extracts on GST activities in *A. gossypii* and *P. solenopsis*

Similarly, the three concentrations of the tested extracts significantly inhibited the GST activities in *A. gossypii* at 24 h ($F=12.48$; $p<0.001$) and 48 h ($F=10.91$; $p<0.001$), and in *P. solenopsis* at 24 h ($F=9.54$; $p<0.001$) and 48 h ($F=7.32$; $p<0.001$), compared to the control and spirotetramat (Figs. 4 and 5).

Discussion

Plants produce a variety of secondary metabolites rich in monoterpenes, sesquiterpenes,

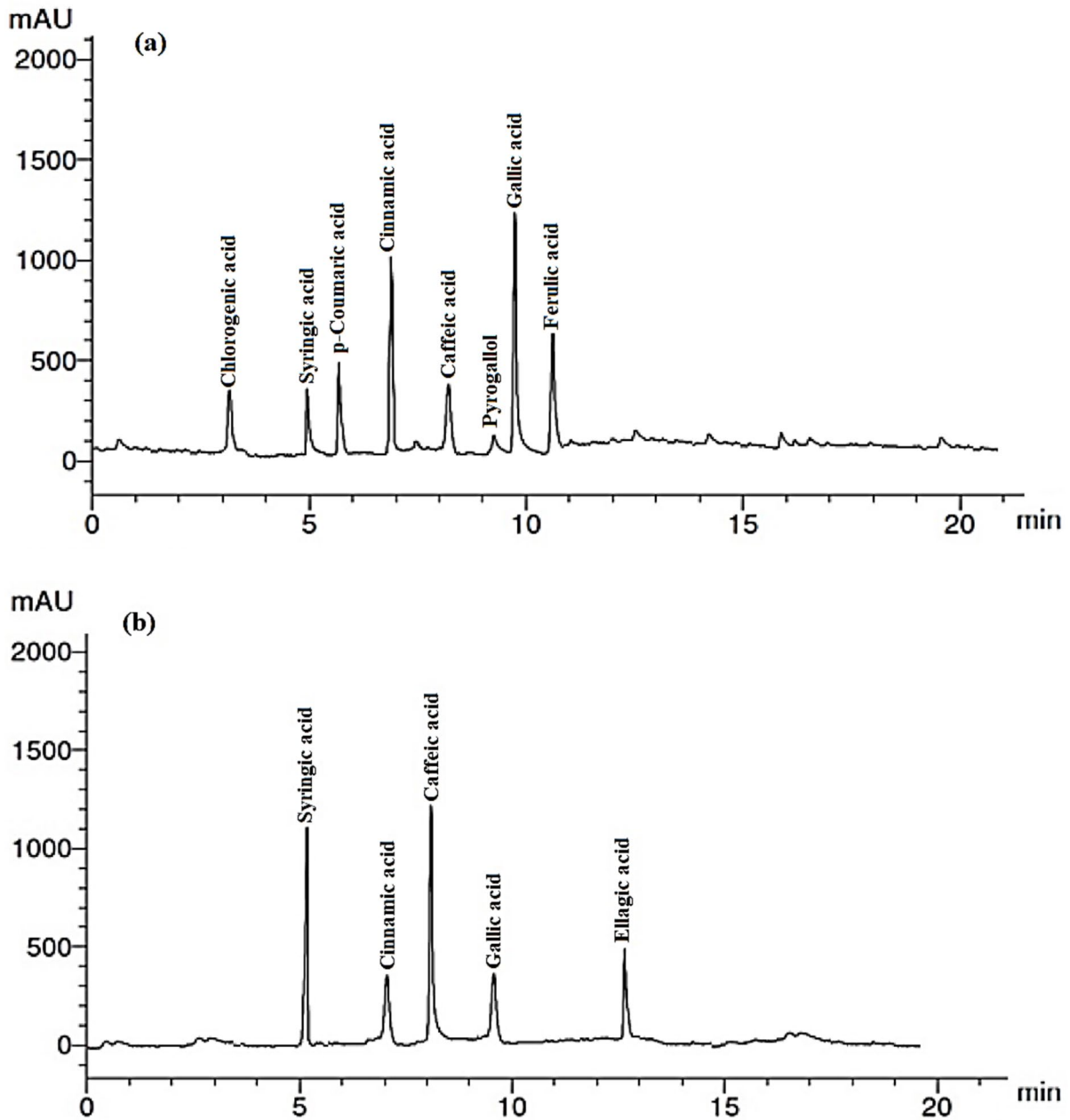


Fig. 1 HPLC chromatograms of the identified phenolic compounds in the methanol extracts. *P. dioscoridis* (a), *U. dioica* (b), *H. albus* (c) and *X. strumarium* (d)

phenylpropenes, phenolic and flavonoid compounds that exhibit good insecticidal activity (Hussein et al., 2023). This study is probably the first of its kind to report the toxic, repellent and biochemical effects of the wild plant extracts of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* against *A. gossypii*

nymphs and *P. solenopsis* adult females. Based on the LC_{50} values, the contact toxicity of the tested plant extracts against *A. gossypii* and *P. solenopsis* after 24 and 48 h of treatment is in the following order: *X. strumarium* extract > *U. dioica* extract > *P. dioscoridis* extract > *H. albus* extract, compared to the

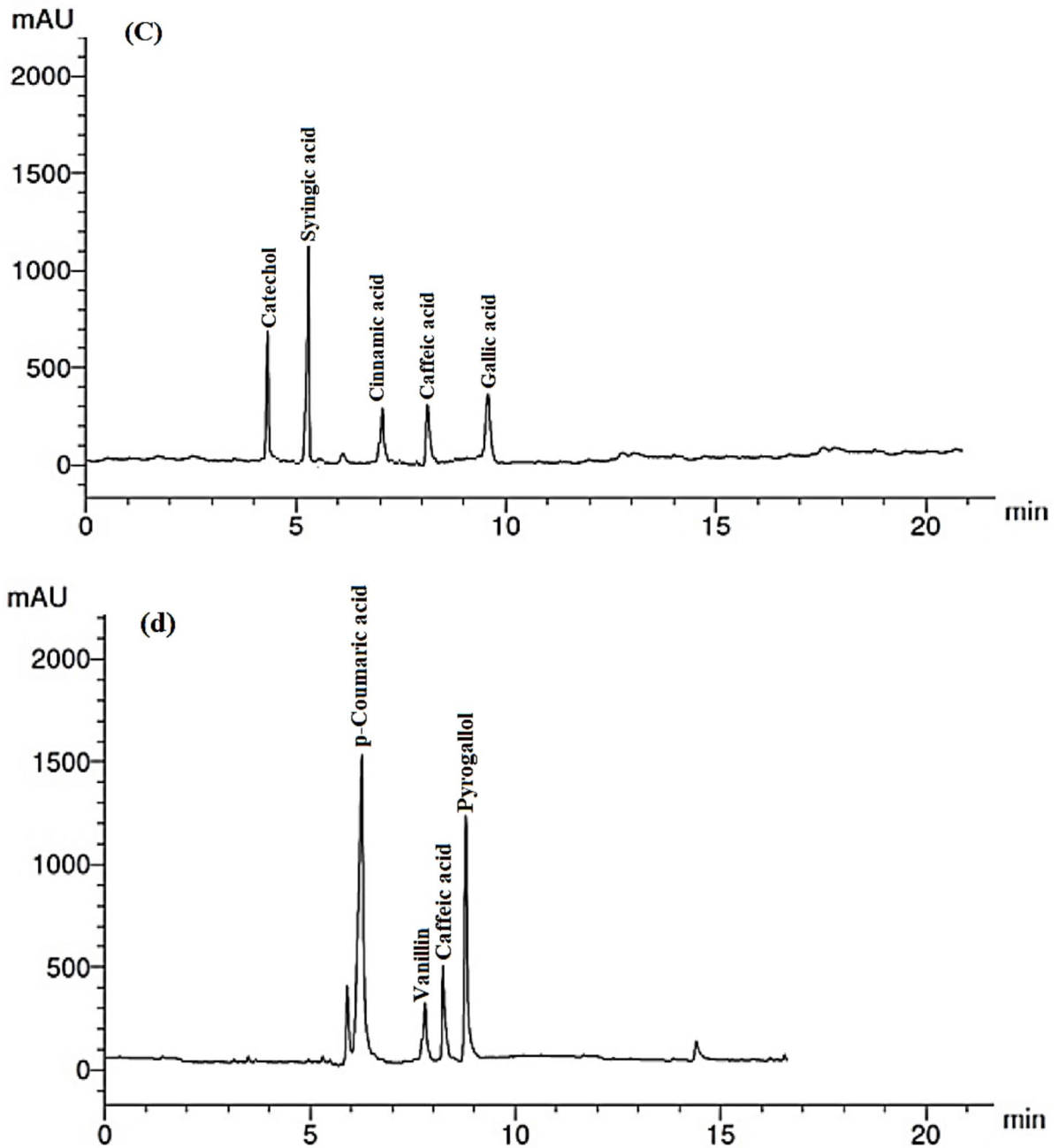


Fig. 1 (continued)

insecticide; spirotetramat. These effects may be due to the presence of bioactive compounds in the methanol extracts. According to the literature, the extracts of the investigated wild plants include a number of bioactive substances, including polyphenolics, alkaloids, flavonoids, essential oils, and other chemicals.

P. dioscoridis methanol extract showed the presence of the phenolic compounds chlorogenic acid, syringic acid, *p*-coumaric acid, cinnamic acid, caffeic acid, pyrogallol, gallic acid and ferulic acid with different concentrations. Gallic acid in the one of the active compounds of *P. dioscoridis* leaf extract

Table 2 Mortality percentages of the 3rd nymphal instar of *A. gossypii* after 24 and 48 h of exposure to the four wild plant extracts compared to the insecticide spirotetramat

Treatment	Conc. (mg/L)	Mortality percentages (mean ± SE)	
		24 h	48 h
<i>U. dioica</i> extract	10	5 ± 0.6 ^k	10 ± 0.9 ^j
	20	15 ± 1.2 ⁱ	25 ± 2.6 ^h
	30	25 ± 0.8 ^h	40 ± 1.1 ^f
	50	40 ± 2.3 ^f	60 ± 1.5 ^d
	75	55 ± 2.2 ^d	70 ± 1.3 ^c
	100	70 ± 1.9 ^b	80 ± 2.5 ^b
<i>H. albus</i> extract	10	3 ± 0.8 ^k	6 ± 1.2 ^j
	20	8 ± 1.4 ^j	15 ± 1.1 ⁱ
	30	15 ± 0.5 ⁱ	25 ± 0.7 ^h
	50	28 ± 1.6 ^g	40 ± 2.3 ^f
	75	45 ± 2.1 ^e	58 ± 1.5 ^d
	100	55 ± 0.9 ^d	70 ± 1.4 ^c
<i>P. dioscoridis</i> extract	10	3 ± 0.4 ^k	8 ± 1.1 ^j
	20	10 ± 1.3 ^j	18 ± 0.9 ⁱ
	30	18 ± 0.7 ⁱ	32 ± 0.8 ^g
	50	34 ± 2.1 ^f	45 ± 1.4 ^e
	75	48 ± 1.6 ^e	60 ± 2.2 ^d
	100	60 ± 2.3 ^{cd}	72 ± 2.0 ^c
<i>X. strumarium</i> extract	10	10 ± 1.2 ^j	18 ± 1.4 ⁱ
	20	24 ± 0.7 ^h	36 ± 1.6 ^f
	30	36 ± 3.2 ^f	48 ± 2.8 ^e
	50	52 ± 1.8 ^d	60 ± 3.0 ^d
	75	65 ± 1.9 ^c	70 ± 1.3 ^c
	100	75 ± 1.2 ^b	80 ± 0.8 ^b
Spirotetramat	10	28 ± 1.3 ^g	32 ± 1.5 ^g
	20	42 ± 1.6 ^{de}	46 ± 0.9 ^e
	30	58 ± 1.2 ^d	65 ± 2.2 ^d
	50	72 ± 1.8 ^b	78 ± 1.1 ^b
	75	100 ± 0.0 ^a	100 ± 0.0 ^a
	100	100 ± 0.0 ^a	100 ± 0.0 ^a

Each concentration was replicated five times. Twenty of the third nymphal instars for each replicate were used. Means within a column followed by the same letter are not significantly different

(Metwally et al., 2022). Gallic acid, ferulic acid, protocatechuic acid, ellagic acid, chlorogenic acid, p-OH-benzoic acid, catechin, caffeic acid, vanillic acid, salicylic acid, p-coumaric acid and cinnamic acid were identified in the extract of *P. dioscoridis* leaves (Elsebaie & Essa, 2022). Lupeol, quercetin, lupeol acetate, stigmasterol, and syringic acid were isolated

from *P. dioscoridis* (Sultan et al., 2024). Kampferol, quercetin, quercetin 3-O-β-D-glucopyranoside, quercetin 3-O-α-L-rhamnopyranosy-(1→6)-β-D-glucopyranoside, and two phenolic acids, caffeic acid and chlorogenic acid, were isolated from the extract (Elshamy et al., 2015). *P. dioscoridis* leaf extracts in ethyl acetate and n-butanol were used to identify phenolic acid derivatives, organic acids, secoiridoids, coumarin derivatives, flavonoids (aglycones and glycosides), and gallotannin derivatives. Among them, dicaffeoylquinic acid, ferulic acid, and caffeic acid 3-sulfate were the most prevalent in the extracts (El-Shazly et al., 2022).

According to El-Hamouly and Ibraheim (2003), *P. dioscoridis*' aerial portions are primarily composed of phenolics and terpenoids and contain 3–5% volatile oil. Phenolics (200 mg/g) were the most prevalent of the four types of secondary metabolites found in *P. dioscoridis* leaf extract. Terpenoids (18 mg/g), flavonoids (9.57 mg/g), and alkaloids (4 mg/g) were the next most abundant category (Metwally et al., 2022). The oil of *P. dioscoridis* showed the presence of many compounds farnesol, longifolene, torreyol, germacrene D 4ol, and isobutyl benzene, with a marked mosquito larvicidal activity against *Culex pipiens* (LC50 71.86 ppm) (Grace, 2002).

Studies on the phytochemistry of *U. dioica* have shown the existence of numerous beneficial chemical substances, including proteins, amino acids, saponins, flavanoids, tannins, sterols, fatty acids, carotenoids, chlorophylls, and phytosterols (Joshi et al., 2014). The following phenolic compounds were identified in *U. dioica* methanol extract: syringic acid, cinnamic acid, caffeic acid, gallic acid, and ellagic acid. Several significant phenolic compounds were isolated from *U. dioica* extracts, including caffeic acid, hydroxybenzoic acid, vanillic acid, coumaric acid, gentisic acid, protocatechuic acid, gallic acid, syringic acid, and quinic acid, as well as several derivatives of caffeic and quinic acid, including quercetin, catechin, pelargonidin, and apigenin in both the glycosidic and non-glycosidic forms, were isolated from stinging nettle leaves, according to recent reviews (Kregiel et al., 2018; Grauso et al., 2020). Fumaric acid, gallic acid, catechin, rutin, myricetin, quercetin, kaempferol and isorhamnetin were isolated from the extract of leaves of *U. dioica* (Sehari et al., 2020). Both cultivated and wild nettle samples' leaves are highly concentrated

Table 3 Contact toxicity of the wild plant extracts compared to the insecticide spirotetramat against the 3rd nymphal instar of *A. gossypii* after 24 and 48 h of treatment

Treatment	Time (h)	LC ₁₀ ^a (mg/L) 95% CL ^b	LC ₂₅ ^c (mg/L) 95% CL	LC ₅₀ ^d (mg/L) 95% CL	LC ₉₀ ^e (mg/L) 95% CL	(Slope ± SE) ^f	(χ ²) ^g
<i>U. dioica</i> extract	24	15.6 11.9–18.9	29.8 25.6–34.2	62.5 54.7–72.1	248.2 186.8–369.6	2.132 ± 0.195	0.775
	48	9.9 7.4–12.5	19.3 15.8–22.4	40.3 35.7–45.5	162.6 128.5–220.7	2.118 ± 0.181	0.386
<i>H. albus</i> extract	24	23.3 18.2–27.4	41.5 36.9–48.3	86.8 72.6–102.7	335.4 240.2–547.4	2.204 ± 0.223	0.161
	48	16.1 12.4–19.5	30.4 26.2–34.5	60.6 54.5–70.3	235.6 179.7–343.6	2.2 ± 0.198	0.560
<i>P. dioscoridis</i> extract	24	20.2 15.6–24.3	38.3 33.2–43.6	78.9 68.5–94.4	310.3 225.1–492.8	2.156 ± 0.211	0.211
	48	12.3 9.2–15.4	24.6 20.7–28.7	56.2 48.6–63.9	240.7 179.6–362.5	1.984 ± 0.184	0.743
<i>X. strumarium</i> extract	24	10.2 7.2–12.8	20.8 16.9–24.3	45.4 40.8–52.1	213.0 160.8–315.5	1.934 ± 0.177	0.08
	48	5.4 3.2–7.6	12.7 9.4–15.9	32.3 28.4–37.6	205.3 149.1–326.5	1.621 ± 0.166	0.453
Spirotetramat	24	3.7 2.3–5.1	8.5 6.4–10.3	21.2 18.1–25.3	122.6 85.6–209.2	1.683 ± 0.181	0.609
	48	2.7 1.6–3.9	6.5 4.6–8.2	17.2 14.5–20.4	109.9 76.6–188.8	1.591 ± 0.176	0.27

^a The concentration causing 10% mortality ^b Confidence limits ^c The concentration causing 25% mortality ^d The concentration causing 50% mortality ^e The concentration causing 90% mortality ^f Slope of the concentration-mortality regression line ± standard error ^g Chi square value

in 2-O-caffeoylmalic acid and chlorogenic acid, which together account for 76.5% and 71.5% of the total phenolics, respectively (Pinelli et al., 2008). Dihydroxybenzoic acid hexoside, hydroxytyrosol hexoside, esculin, *p*-coumaric acid hexoside, caffeic acid, 2-caffeoylisocitric acid cyclodimer, 2-caffeoylisocitric acid, 7'-hydroxylariciresinol-7'-O-hexoside, *p*-coumaroylisocitric acid, neo-olivul 9-O-hexoside, 2-feruloylisocitric acid, luteolin 6-C-hexoside, luteolin O-deoxyhexosyl-C-hexoside, apigenin 6,8-diC-hexoside, and others were isolated from the leaves of *U. dioica* (Brahmi-Chen-douh et al., 2021). Nettles also contain fatty acids, with unsaturated fatty acids being the most prevalent. α -linolenic acid, palmitic acid, and cis-9,12-linoleic acid are the main fatty acids (Simopoulos, 2003).

The qualitative examination of *U. dioica* extract mostly reveals the presence of flavonoids such as rutin, isoquercetin, and isorhamnetin rutinoside, as well as certain caffeic acid isomers, both free and in combination with quinic or malic acid (Frag et al.,

2013). Several polyphenolic compounds including caffeic acid, caffeoylquinic acid, ferulic acid, rutin and isoquercetin were isolated from leaves of *U. dioica* (Komes et al., 2011; Garcia et al., 2021).

Phenolic compounds catechol, syringic acid, cinnamic acid, caffeic acid and gallic acid were identified in the methanol extract from *H. albus*. The ethanol extract from *H. albus* extract identified 18 distinct phenolic compounds, among these, *p*-coumaric acid, gallic acid, luteolin, apigenin, and rutin were identified as the most abundant polyphenolic molecules in the extract (Lekmine et al., 2023). The methanolic extract demonstrated various phenolic components, such as methyl salicylate, methyl ferulate, 4-hydroxycinnamic acid-ester, and ferulic acid, and it also showed antifeedant activity when applied to *Spodoptera littoralis* larvae in their fourth instar (Elsharkawy et al., 2018). The methanol extract of the aerial parts of showed the presence of caffeic, ferulic, *trans*-cinnamic acids and quercetin (Ayari-Guentri et al., 2017).

Table 4 Mortality percentages of the adult females of *P. sole-nopsis* after 24 and 48 h of exposure to the four wild plant extracts compared to the insecticide spirotetramat

Treatment	Conc. (mg/L)	Mortality percentages (mean $\pm$ SE)	
		24 h	48 h
<i>U. dioica</i> extract	10	3 $\pm$ 0.9 ^j	3 $\pm$ 1.4 ^k
	20	12 $\pm$ 1.8 ⁱ	12 $\pm$ 0.7 ^j
	30	21 $\pm$ 2.3 ^h	24 $\pm$ 1.5 ⁱ
	50	32 $\pm$ 2.1 ^g	45 $\pm$ 0.8 ^f
	75	48 $\pm$ 1.4 ^e	60 $\pm$ 1.1 ^d
	100	60 $\pm$ 1.8 ^c	75 $\pm$ 1.3 ^c
<i>H. albus</i> extract	10	2 $\pm$ 1.3 ^j	6 $\pm$ 1.2 ^k
	20	9 $\pm$ 1.1 ⁱ	14 $\pm$ 2.1 ^j
	30	16 $\pm$ 1.6 ^h	24 $\pm$ 1.3 ⁱ
	50	28 $\pm$ 2.5 ^g	36 $\pm$ 1.6 ^g
	75	43 $\pm$ 1.9 ^f	52 $\pm$ 1.2 ^e
	100	55 $\pm$ 1.2 ^d	70 $\pm$ 1.9 ^c
<i>P. dioscoridis</i> extract	10	2 $\pm$ 0.6 ^j	5 $\pm$ 1.5 ^k
	20	10 $\pm$ 1.5 ⁱ	15 $\pm$ 2.4 ^j
	30	18 $\pm$ 2.6 ^h	26 $\pm$ 1.8 ⁱ
	50	32 $\pm$ 1.4 ^g	38 $\pm$ 1.1 ^g
	75	48 $\pm$ 1.8 ^e	52 $\pm$ 1.7 ^e
	100	60 $\pm$ 1.3 ^c	70 $\pm$ 0.9 ^c
<i>X. strumarium</i> extract	10	10 $\pm$ 2.2 ⁱ	14 $\pm$ 1.3 ^j
	20	22 $\pm$ 2.9 ^h	30 $\pm$ 2.2 ^h
	30	32 $\pm$ 1.6 ^g	45 $\pm$ 1.2 ^f
	50	46 $\pm$ 0.8 ^e	60 $\pm$ 1.5 ^d
	75	62 $\pm$ 1.4 ^c	72 $\pm$ 1.8 ^c
	100	72 $\pm$ 1.2 ^b	80 $\pm$ 1.6 ^b
Spirotetramat	10	18 $\pm$ 0.7 ^h	24 $\pm$ 1.1 ⁱ
	20	36 $\pm$ 1.6 ^f	42 $\pm$ 1.3 ^f
	30	52 $\pm$ 1.3 ^d	55 $\pm$ 1.4 ^e
	50	70 $\pm$ 0.9 ^b	75 $\pm$ 1.2 ^c
	75	100 $\pm$ 0.0 ^a	100 $\pm$ 0.0 ^a
	100	100 $\pm$ 0.0 ^a	100 $\pm$ 0.0 ^a

Each concentration was replicated five times. Twenty of the adult females for each replicate were used. Means within a column followed by the same letter are not significantly different

The methanol extract of *X. strumarium* showed the presence of phenolic compounds: *p*-coumaric acid, vanillin, caffeic acid and pyrogallol. The presence of *trans*-cinnamic acid and the phenolic compounds caffeic acid, chlorogenic acid, ferulic acid, gallic acid, quercetin, rutin, and protocatechuic acid was measured in the methanolic and ethanolic extracts of *X. strumarium* (Scherer & Godoy, 2014).

Different studies have shown the insecticidal potential of the tested plant extracts against several pests. For example, the nematocidal effect of *U. dioica* against root-knot nematodes, *Meloidogyne incognita* was observed (Ismail et al., 2020). The ethanolic extract of *U. dioica* showed the maximum mortality rate (100%) against third larval instar of *Tribolium confusum* at 1.5 mg/mL (Rasheed et al., 2022). The aqueous extract of nettle was successful exhibited in reducing the two aphids, *Macrosiphum euphorbiae* and *Aulacorthum solani* density (Florrian et al., 2023). Stinging nettle has also been demonstrated various pharmacological activities such as antioxidant, antibacterial, antimicrobial, and antifungal (Sehari et al., 2020; Behiry et al., 2022). Tannins extracted from *U. dioica* leaves had potential anti-feedant activity with an EC₅₀ of 33.034 μ g/g against larvae of cotton leafworm *S. littoralis* (El-Aswad et al., 2023). After 48 h, applying nettle leaf extract at a dosage of 15 mL/L killed all of the tobacco aphids *Myzus nicotianae* (Shazdeahmadi, 2021).

It was revealed that the larvicidal effect of the methanol extract of *Hyoscyamus niger* aerial parts against *Anopheles* spp. mosquito larvae was observed with an LC₅₀ value of 0.74 mg/mL after 72 h of exposure (Behravan et al., 2017). Furthermore, the insecticidal activity of *H. niger* seeds against the sheep blow fly, *Lucilia sericata* larvae was stated (Küpeli Akkol et al., 2020). Also, the efficacy of the acetone and methanol extracts of the Egyptian henbane, *H. muticus* leaves, and flowers against *Tetranychus urticae* Koch. was observed (Abou-Shosha, 2020).

Conyza dioscoridis aerial parts extract showed insecticidal activity against the 4th larval instars of the cotton leafworm, *Spodoptera littoralis* (Matloub et al., 2021). The larvicidal effect of the aerial part of *Pluchea sp.* essential oil against the 2nd instar larvae of fall armyworm, *S. frugiperda* was investigated (Gonfa et al., 2022). The insecticidal activity of *C. dioscoridis* essential oil against *Culex pipiens* was also reported (Opiyo et al., 2023).

The aqueous extracts of *X. strumarium* leaves have promising potential as an effective insecticide against pulse beetle, *Callosobruchus chinensis* (Roy et al., 2014), where the insect mortality was accounted highest (72.6%) with 4% extract at 4 days after treatment. Furthermore, the fruit extracts demonstrated effects on *C. chinensis* mortality, repellency, fecundity, and adult emergence in addition to preventing

Table 5 Contact toxicity of the wild plant extracts compared to the insecticide spirotetramat against the adult females of *P. solenopsis* after 24 and 48 h of treatment

Treatment	Time (h)	LC ₁₀ ^a (mg/L) 95% CL ^b	LC ₂₅ ^c (mg/L) 95% CL	LC ₅₀ ^d (mg/L) 95% CL	LC ₉₀ ^e (mg/L) 95% CL	(Slope ± SE) ^f	(χ ²) ^g
<i>U. dioica</i> extract	24	18.5 14.2–22.5	36.4 31.5–41.8	76.2 65.4–92.3	330.4 235.3–541.2	2.047 ± 0.204	0.576
	48	16.8 14.3–20.2	30.8 26.9–34.6	56.4 52.1–63.8	180.7 145.9–240.8	2.548 ± 0.211	0.366
<i>H. albus</i> extract	24	22.3 17.4–26.8	43.2 37.6–49.4	90.8 77.4–111.9	368.4 257.3–626.9	2.105 ± 0.218	0.302
	48	14.8 10.9–18.4	30.4 25.7–35.0	67.5 58.7–80.6	310.8 221.9–505.6	1.939 ± 0.190	0.721
<i>P. dioscoridis</i> extract	24	20.9 16.3–25.4	42.5 35.7–47.2	88.3 75.4–108.2	370.9 258.6–636.8	2.053 ± 0.212	0.409
	48	15.4 11.7–18.9	30.3 25.8–34.7	64.3 56.2–75.1	266.5 197.4–407.2	2.072 ± 0.194	0.934
<i>X. strumarium</i> extract	24	10.7 7.6–13.6	22.6 18.5–26.5	52.0 45.4–60.6	253.8 185.6–396.4	1.862 ± 0.178	0.593
	48	8.0 5.6–10.4	16.3 13.1–19.4	36.2 31.7–41.1	163.1 127.2–229.3	1.958 ± 0.174	0.329
Spirotetramat	24	6.3 4.5–8.0	12.8 10.6–15.0	28.4 24.5–33.7	127.6 91.9–205.5	1.963 ± 0.198	0.527
	48	5.6 4.0–7.1	11.2 9.1–13.1	24.5 21.2–28.5	106.9 79.3–163.6	1.996 ± 0.194	0.653

^a The concentration causing 10% mortality ^b Confidence limits ^c The concentration causing 25% mortality ^d The concentration causing 50% mortality ^e The concentration causing 90% mortality ^f Slope of the concentration-mortality regression line ± standard error ^g Chi square value

Table 6 Repellent effect of the wild plant extracts compared to the insecticide spirotetramat on *A. gossypii* and *P. solenopsis* after 24 and 48 h of treatment

Treatment	Conc. (mg/L)	Repellency percentage (RP)			
		<i>A. gossypii</i>		<i>P. solenopsis</i>	
		24 h	48 h	24 h	48 h
<i>U. dioica</i> extract	LC ₁₀	35.7 ± 2.6 ^f	31.4 ± 3.2 ^f	30.9 ± 5.4 ^f	29.3 ± 5.4 ^f
	LC ₂₅	38.3 ± 4.2 ^e	36.9 ± 5.3 ^e	35.6 ± 4.2 ^e	35.2 ± 3.3 ^d
	LC ₅₀	46.2 ± 4.8 ^c	42.6 ± 5.5 ^c	43.5 ± 3.9 ^c	40.9 ± 3.8 ^c
<i>H. albus</i> extract	LC ₁₀	28.4 ± 6.3 ^h	25.8 ± 3.6 ^h	26.2 ± 4.5 ^g	24.6 ± 5.2 ^g
	LC ₂₅	33.2 ± 5.6 ^g	30.7 ± 2.1 ^f	30.4 ± 2.3 ^f	27.3 ± 4.5 ^f
	LC ₅₀	38.8 ± 2.9 ^e	36.3 ± 4.5 ^e	35.8 ± 3.4 ^e	35.5 ± 3.6 ^d
<i>P. dioscoridis</i> extract	LC ₁₀	32.6 ± 3.7 ^g	28.6 ± 4.3 ^g	30.3 ± 2.5 ^f	28.2 ± 4.9 ^f
	LC ₂₅	36.2 ± 3.3 ^f	35.4 ± 5.2 ^e	34.7 ± 4.3 ^e	32.8 ± 4.4 ^e
	LC ₅₀	45.3 ± 5.1 ^c	43.2 ± 4.5 ^c	42.8 ± 5.6 ^c	40.3 ± 5.3 ^c
<i>X. strumarium</i> extract	LC ₁₀	42.7 ± 5.4 ^d	39.5 ± 3.3 ^d	38.4 ± 3.9 ^d	36.4 ± 3.4 ^d
	LC ₂₅	58.6 ± 4.3 ^b	56.2 ± 5.4 ^b	54.2 ± 5.1 ^b	53.7 ± 6.3 ^b
	LC ₅₀	63.2 ± 5.5 ^a	58.3 ± 4.8 ^a	60.3 ± 2.8 ^a	58.2 ± 5.8 ^a
Spirotetramat	LC ₁₀	68.4 ± 2.6 ^c	59.4 ± 4.3 ^c	64.8 ± 4.2 ^c	60.3 ± 4.8 ^c
	LC ₂₅	72.3 ± 3.8 ^b	64.3 ± 3.6 ^b	70.9 ± 3.4 ^b	62.4 ± 3.2 ^b
	LC ₅₀	78.5 ± 4.2 ^a	69.6 ± 5.2 ^a	76.2 ± 4.6 ^a	65.8 ± 5.5 ^a

Data are presented as mean ± SE of 5 replications. Means within a column followed by the same letter are not significantly different. The repellency percentage (RP) was calculated (Liu et al., 2013): $RP (\%) = [(Nc - Nt) / (Nc + Nt)] \times 100$; Where Nc was the number of insects presents in the control half, Nt was the number of insects presents in the treated half

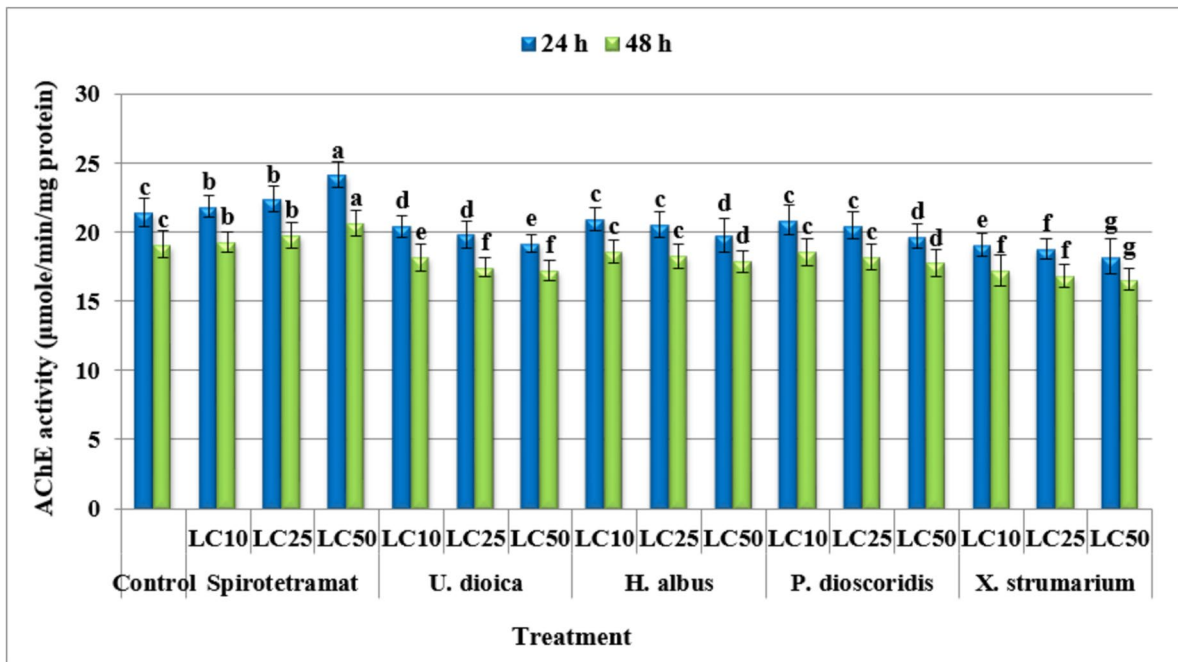


Fig. 2 Effect of the different concentrations of the wild plant extracts compared to the insecticide spirotetramat in the acetylcholinesterase (AChE) activity of *A. gossypii* after 24 and 48 h

of treatment. Columns indicate means $\pm$ SE. Different letters in the top refer to the means are significantly different by Tukey's honestly significant difference test ($p < 0.05$)

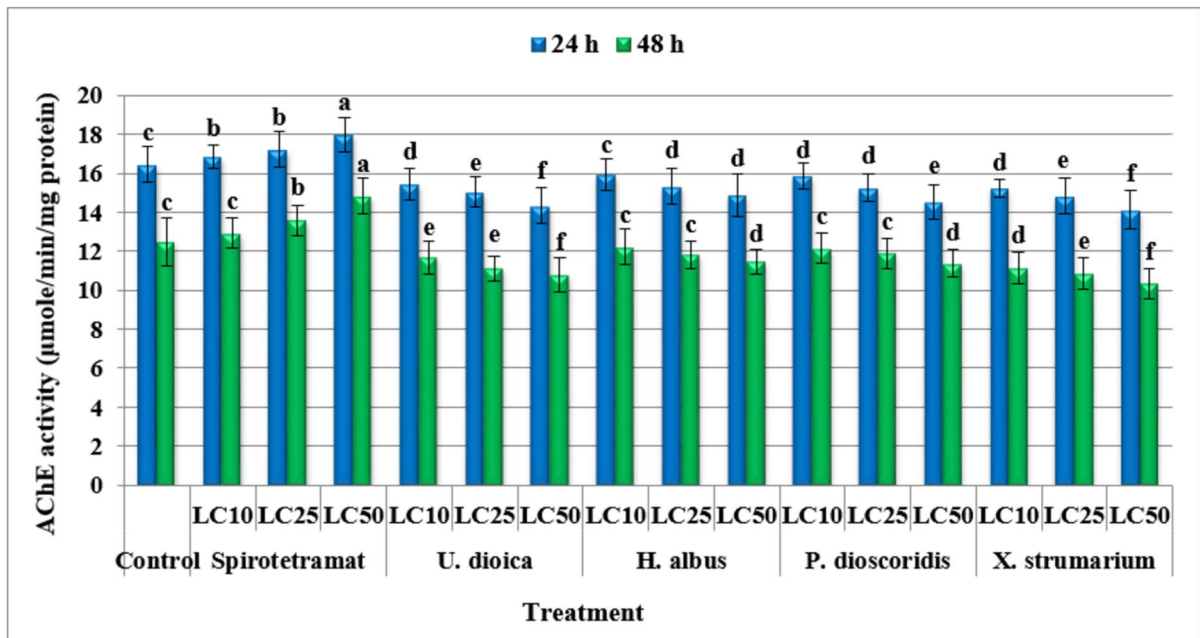


Fig. 3 Effect of the different concentrations of the wild plant extracts compared to the insecticide spirotetramat in the acetylcholinesterase (AChE) activity of *P. solenopsis* after 24 and

48 h of treatment. Columns indicate means $\pm$ SE. Different letters in the top refer to the means are significantly different by Tukey's honestly significant difference test ($p < 0.05$)

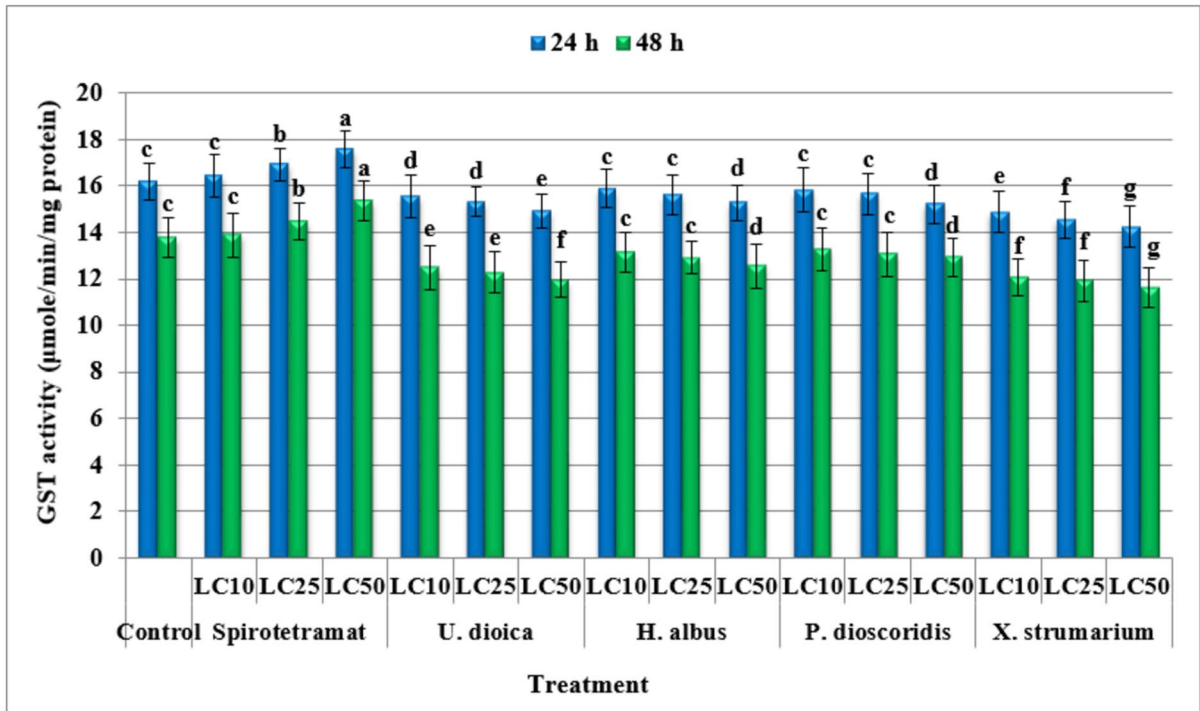


Fig. 4 Effect of the different concentrations of the wild plant extracts compared to the insecticide spirotetramat in the glutathione-S-transferase (GST) activity of *A. gossypii* after 24

and 48 h of treatment. Columns indicate means $\pm$ SE. Different letters in the top refer to the means are significantly different by Tukey's honestly significant difference test ($p < 0.05$)

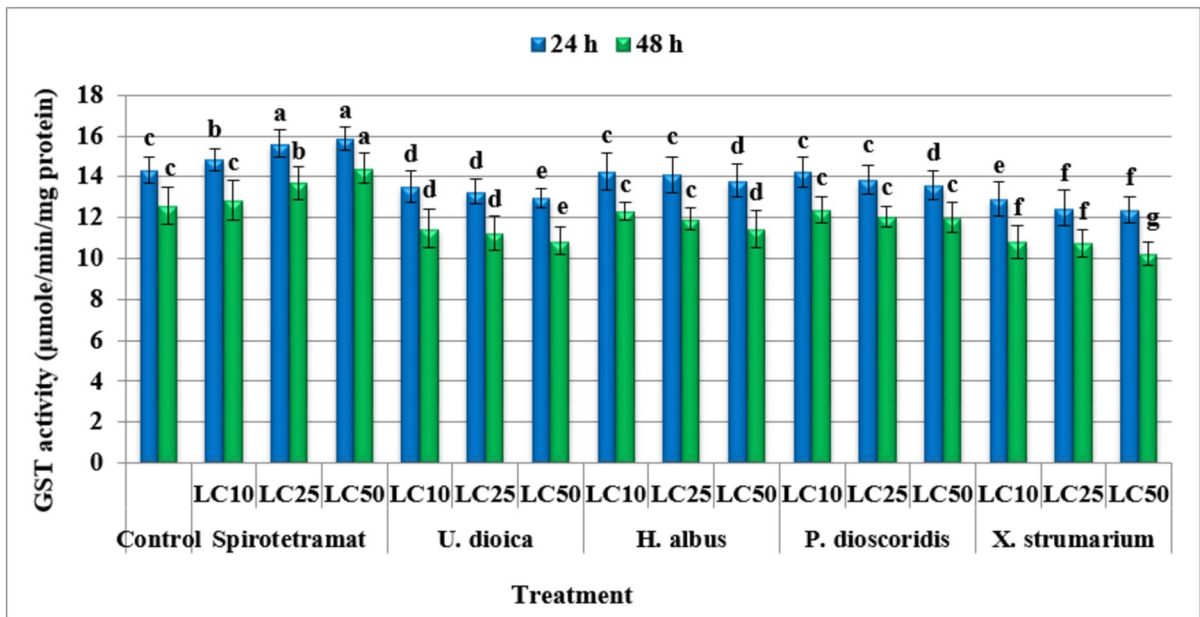


Fig. 5 Effect of the different concentrations of the wild plant extracts compared to the insecticide spirotetramat in the glutathione-S-transferase (GST) activity of *P. solenopsis* after 24

and 48 h of treatment. Columns indicate means $\pm$ SE. Different letters in the top refer to the means are significantly different by Tukey's honestly significant difference test ($p < 0.05$)

damage to pulse grains. Of these, the 4% extract exhibited the highest rates of mortality (26%) and repellency (53.3%) at two and three hours after treatment, respectively (Roy et al., 2012).

Furthermore, the acetone, methanol and water extracts of *X. strumarium* were observed mosquitocidal activity against *Culex* mosquito larvae and pupae (Roba et al., 2015). Another study showed the insecticidal activity of ethanol extract of *X. strumarium* against *Myzus persicae* nymphs and adults with 89 and 82% mortality, respectively at the highest concentration (Erdoğan & Yıldırım, 2016). The larvicidal activity of hexane and ethanol extracts prepared from the leaves and stems of *X. strumarium* were observed against dengue fever mosquito, *Aedes aegypti*. (Sharma et al., 2016). Additionally, the insecticidal properties of *X. strumarium* against banana leaf and fruit scarring beetle (*Basilepta subcostatum* Jacoby) was reported (Gogoi et al., 2021).

According to the present study, the tested plant extracts with the three concentrations compared to the spirotetramat revealed 28.4–63.2% repellency for *A. gossypii* and 26.2–60.3% repellency for *P. solenopsis* at 24 h, but decreased with time. Similar findings were also observed, where the highest repellency of plant extracts (99.0 and 97.0%) was recorded against *A. gossypii* and *P. solenopsis* at 24 h (Singh et al., 2012).

Recently, there has been a focus on developing AChE inhibitors derived from plants for insecticidal use. The inhibitory impact on AChE activity entails the interaction between bioactive molecules such as phenolic compounds and insect tissues, which possess diverse hydrophilic–hydrophobic characteristics, facilitating their penetration through insect cuticles and influencing physiological processes (López & Pascual-Villalobos, 2010). Phenolic compounds seemed able to form complexes with cuticle lipid layers, causing loss of membrane integrity. Once they penetrated the insect body, phenolic compounds reached the nervous system and inhibited the activity of AChE. Phenolic compounds have also been found to inhibit the activity of glutathione *S*-transferases enzyme (which detoxify insecticides) thereby, enhancing insecticidal properties (Wang et al., 2014).

Among the various detoxifying enzymes, AChE and GST are the primary target enzymes of various researchers to study the biochemical changes in insects. Hence, in the present study, the three

concentrations of the tested extracts significantly inhibited the enzymes activities at 24 and 48 h in *A. gossypii* and *P. solenopsis* compared to the spirotetramat. Their inhibition of the detoxifying enzymes activities were distinctly correlated with their contact toxic effects. Similarly, it was found that the activities of AChE and GST in the green peach aphid, *Myzus persicae* were substantially inhibited by the plant extracts, with time-dependent effects (Zhou et al., 2016). Also it was exhibited that some pure compounds of essential oils significantly inhibited the enzyme activities of AChE and GST in the mealybug, *P. lilacinus* (Arokiyaraj et al., 2022). Insecticide-detoxifying enzymes are important for the metabolism of xenobiotics in insects. The induction of these detoxifying enzymes is related to the resistance of insects to insecticides (Gong et al., 2021).

Conclusions

The present study showed that the different concentrations of *U. dioica*, *H. albus*, *P. dioscoridis*, and *X. strumarium* extracts have toxic and repellent effects on *A. gossypii* and *P. solenopsis* after 24 and 48 h of treatment. This study revealed that the toxicity of the tested extracts could be associated with their high content of bioactive molecules such as phenolic compounds and their AChE and GST inhibition potential. Accordingly, the tested plant extracts may be recommended as an efficient source of promising phytochemical compounds exhibiting high insecticidal activity for aphid and mealybug management.

Author contributions S.E.E., M.E.T., and M.Z.M.S did the experimental studies and laboratory work. S.E.E. and M.Z.M.S did the prepared figures and statistical analysis. S.E.E., M.E.T., and M.Z.M.S have equal contributors to writing the manuscript. All authors read and approved the final manuscript.

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Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

Ethical approval Not applicable.

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