http://ijmpes.com

doi:10.34172/ijmpes.6297

Open Access

Original Article

APMI Press
Aras Part Medical International Press
A scientific publishing imprint of PMC PharmaceutiqueFrance

Int J Med Parasitol Epidemiol Sci 2026;7(3): 213-221
eISSN 2766-6492

International Journal of
Medical Parasitology & Epidemiology Sciences

Attractant and Repellent Effect of *Syzygium aromaticum*, *Cinnamomum verum* and *Allium cepa* Extracts in Controlling the Ant *Solenopsis invicta*

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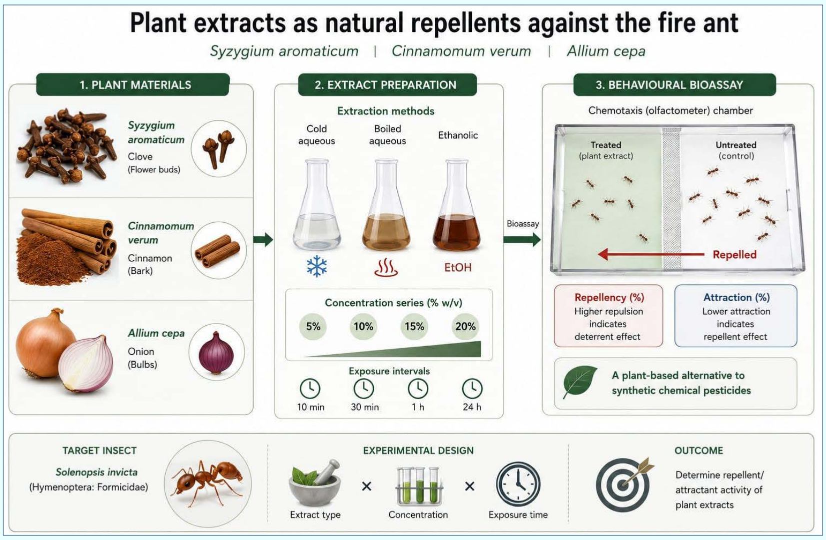
Abstract

Introduction: Ants are insect pests that can cause economic and environmental damage, as well as transmit pollutants and microorganisms, necessitating the search for safe alternatives to traditional chemical pesticides. Medicinal and aromatic plants are an important source of active compounds that influence insect behavior, with their effectiveness varying depending on the plant species, extraction method, and solvent, concentration, and exposure duration. The current study aimed to evaluate the repellent efficacy of extracts from several aromatic and medicinal plants, including *Syzygium aromaticum*, *Cinnamomum verum* and *Allium cepa*, against the ant *Solenopsis invicta*, while also investigating the effect of extract type, concentration, and exposure duration on ant behavior.



Methods: Worker ants were collected from three areas in the Karbala Governorate. The study extended from December 2025 to March 2026. Plants were collected from local markets in the province, and the experiment was conducted at the Core Laboratory in the Saif Saad area of Karbala, Department of Biology, and College of Education for Pure Sciences, University of Karbala. The study adopted an experimental approach to evaluate three types of plant extracts: alcoholic, boiled aqueous, and cold aqueous, at four concentrations: 5%, 10%, 15%, and 20%. The ants' response was monitored after 10 minutes, 30 minutes, one hour, and 24 hours. The repellency and attraction rates were measured, and the differences were statistically analyzed at a probability level of 0.05.

Results: The results showed significant differences in the effectiveness of the extracts depending on the plant species, extract type, concentration, and exposure time. The alcoholic extract was generally the most effective. Repellent efficacy increased with increasing concentration and gradually decreased with increasing exposure time. *S. aromaticum* exhibited the highest ant-repelling efficacy, averaging 94.25%, followed by *C. verum* at 87.08%, and *A. cepa* at 72.50%. The highest overall repellent rate, 84.46%, was recorded after 10 minutes, with a clear inverse relationship between repellent and attractant rates.

Conclusion: The study concluded that plant extracts, particularly the 20% alcoholic extract of *S. aromaticum*, possess promising ant-repellent efficacy and could represent a suitable plant-based alternative to traditional chemical pesticides.

Keywords: *Syzygium aromaticum*, *Cinnamomum verum*, *Allium cepa*, Plant extracts, Repellent activity, *Solenopsis invicta*

Received: April 15, 2026, **Revised:** June 11, 2026, **Accepted:** July 24, 2026, **ePublished:** September 18, 2026

Introduction

Ants of the family Formicidae are among the most successful and widespread social insects in terrestrial ecosystems. They play important ecological roles, such as soil aeration, decomposition of organic matter, and nutrient recycling, as well as contributing to the maintenance of ecological balance (1). Despite this ecological importance, many ant species have become pests with economic and health impacts, causing direct and indirect damage to agricultural crops. They also have symbiotic relationships with some sap-sucking insects, such as aphids, leading to increased population density and losses in agricultural production (2). Furthermore, ants act as mechanical vectors for a number of pathogens in homes, restaurants, and healthcare facilities, making them insects that require the development of effective and safe control methods (3).

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For decades, ant and other insect control programs have relied on broad-spectrum synthetic chemical pesticides. However, their overuse has led to numerous environmental and health problems, most notably soil and water pollution, harm to non-target organisms, and ecological imbalance. Furthermore, resistance has developed in many insect species, including some ant species such as *Solenopsis invicta*, reducing the effectiveness of many commonly used pesticides and increasing the need for safer and more sustainable alternatives (4).

With the global trend toward implementing integrated pest management principles, interest in finding natural alternatives to chemical pesticides has grown. Plant extracts have garnered significant attention due to their broad biological activity, low toxicity, rapid decomposition in the environment, and limited impact on non-target organisms compared to traditional pesticides (5).

Plant extracts are a rich source of active secondary compounds, such as terpenes, phenols, and flavonoids. Alkaloids and volatile oils affect the sensory and nervous systems of insects, eliciting various behavioral responses such as attraction, repulsion, feeding inhibition, or reduced motor activity. The type of response depends on the nature and concentration of the chemical compounds, the method of extraction, and the target insect species. Numerous studies have demonstrated the potential of these compounds in developing effective methods for attracting insects to traps or deterring them from protected areas, thereby enhancing the efficiency of integrated pest management programs and reducing reliance on chemical pesticides (6,7). The efficacy of plant extracts in eliciting behavioral responses in insects varies depending on several factors, including the plant species, the part of the plant used, the type of solvent, the extraction method, the extract concentration, the duration of exposure, and the physiological and behavioral differences between insect species. Therefore, a comprehensive evaluation of these factors is essential to identifying the most effective extracts for attracting or repelling insects, particularly those that rely heavily on chemical signals, such as ants. Medicinal and aromatic plants, such as *S. aromaticum*, *C. verum* and *A. cepa*, are receiving increasing attention due to their content of active compounds, including eugenol, cinnamaldehyde, and sulfur compounds. These compounds have demonstrated varying effects on insect behavior, making them promising candidates for developing safer and more sustainable natural pest control methods (5).

Aim of the study

To evaluate the attractant and repellent effects of plant extracts (*Allium cepa* L., *Syzygium aromaticum* L., *Cinnamomum verum*) and to identify the most effective extracts in inducing attraction and repulsion.

Materials and Methods

Insect collection

Worker ants and queens were collected from three different areas in the holy city of Karbala (Al-Husayniyah District, Tuwayrij District, and the city center) between December 2025 and March 2026. The field collection process followed established methods to ensure the acquisition of live and healthy specimens, based on previously approved collection and rearing protocols (8, 9).

Collection of plant samples

Three types of medicinal and aromatic plants were used in this study: cinnamon, clove, and onion (Table 1). Fresh onion bulbs, cinnamon bark, and unopened clove flower buds were obtained from local commercial markets in Karbala Governorate during the period from December 2025 to February 2026. The plants were collected based on standard protocols described previously (10, 11).

Preparation of plant extracts

Preparation of cold and boiled aqueous extracts

The cold and boiled aqueous extracts were prepared according to a previously described method (12), with the modification reported earlier (13).

Preparation of ethyl alcohol extracts

The preparation of the alcoholic extract was carried out according to previously described methods (14). The prepared aqueous and alcoholic extracts are shown in Figure 1.

Precipitation (inferential) tests

To detect the active compounds in the plant extracts, a series of precipitation tests was conducted. Tannins were detected using ferric chloride, flavonoids using the Shinoda test, reducing sugars using Benedict's reagent, terpenes and phenols using ferric chloride, and coumarins following previously described procedures (15). Saponins were detected using the foam test, resins and proteins using the biuret test, alkaloids using Mayer's reagent, steroids using the Liebermann–Burchard reagent, glycosides using the Keller–Kiliani reagent, and anthraquinones by the Bornträger test, as described previously (16).

Measuring the insect response to plant materials in terms of attraction and repulsion

The chemotaxis apparatus was designed locally from transparent glass with dimensions of 48 cm in length, 20 cm in width, and 20 cm in height, to facilitate observation of insect movement during the experiment (Figure 2). The apparatus was used to measure the insect response to plant materials in terms of attraction or repulsion, based on the principle used in earlier studies (17).

Study of the attraction and repulsion ratio of plant extracts to ants

The attraction and repulsion ratios of plant extracts were studied using an olfactometer, as described in earlier studies (17, 18). The attraction and repellency rates were calculated as follows:

Attraction rate (%) = (Number of insects moving toward the tested substance at 25 cm from the centre / Total

Table 1. Plant species used for the preparation of the extracts

No	Families	Common name	Scientific name	Plant part	Collection site
1	Myrtaceae	Clove	*S. aromaticum*	Unopened flower buds	Markets
2	Amaryllidaceae	Onion	*A. cepa*	Bulbs	From the orchards of Al-Husayniyah
3	Lauraceae	Cinnamon	*C. verum*	Bark	Markets

Figure 1. Aqueous and alcoholic extracts of the plants used

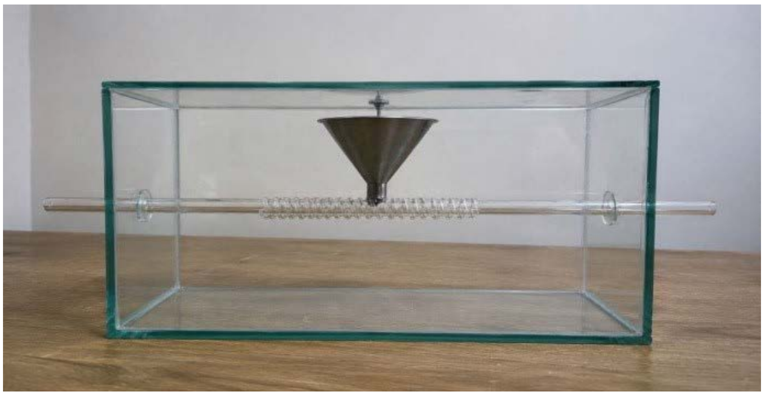

Figure 2. Chemotaxis apparatus used to measure the attraction and repulsion response of ants

number of insects) × 100

Repellency rate (%) = (Number of insects moving away from the tested substance at 25 cm from the centre / Total number of insects) × 100

Results

Effect of S. aromaticum extracts in repelling and attracting ants

The results in Table 2 show that *S. aromaticum* extract had a clear effect in repelling ants, while the attraction rate gradually decreased with increasing concentration, indicating that the repellent effect depends primarily on both concentration and time. The results also showed significant differences between the types of extracts, concentrations, and time periods. The LSD values at the probability level of 0.05 were 0.4997 for the extract, 0.577 for the concentration, and 0.577 for the time period, while the three-way interaction value (extract × concentration × time period) was 1.9987, confirming that the effect of clove varies according to the type of extract, concentration, and time period.

By comparing the types of extracts, the alcoholic extract

Table 2. Effectiveness of *S. aromaticum* extracts in repelling and attracting ants

Extract Type	Conce	Repellency ratio: Time period: After 10 min	After 30 min	After An hour	After24h	Average Extract effect	Attraction ratio: Time period: After 10 min	After 30 min	After An hour	After 24h	Average Extract effect
Alcoholic	5%	75.00	68.66	62.00	55.66	82.31	25.00	31.34	38.00	44.33	17.64
	10%	87.33	84.00	81.33	76.00		12.66	16.00	18.66	24.00	
	15%	96.00	87.00	86.00	81.00		4.00	13.00	14.00	19.00	
	20%	98.66	95.00	92.33	91.00		1.33	5.00	7.66	9.00	
Boiling Water	5%	73.00	66.00	58.00	54.33	77.85	27.00	34.00	42.00	45.66	22.14
	10%	82.00	78.33	76.00	71.00		18.00	21.66	24.00	29.00	
	15%	85.00	82.66	81.00	79.00		15.00	17.33	19.00	21.00	
	20%	93.00	90.66	89.00	86.66		7.00	9.33	11.00	13.33	
Cold Water	5%	66.33	62.00	54.66	51.44	70.98	33.66	38.00	45.33	49.00	29.04
	10%	75.00	73.66	71.33	65.66		25.00	26.33	28.66	34.33	
	15%	77.66	75.66	75.33	72.33		22.33	24.33	24.66	27.66	
	20%	82.33	79.66	77.33	75.33		17.66	20.33	22.66	24.66	
Time effect rate		82.61	78.61	75.36	71.61		17.38	21.38	24.63	28.41	
Concentration effect rate		5%	10%	15%	20%		5%		10%	15%	20%
		62.25	76.80	81.55	87.58		37.77		23.19	18.44	12.41
L.S.D 0.05		Extract type	Conce	Time period	Extract × Conc. × Time		Extract Type		Conce	Time period	Extract × Conc. × Time
		0.4997	0.577	0.577	1.9987		0.4928		0.569	0.569	1.9712

achieved the highest overall repellent rate of 82.31%, followed by the boiled aqueous extract at 77.85%, and then the cold aqueous extract at 70.98%.

Effect of C. verum extracts on ant repelling and attracting

Table 3 shows that the ants' response to *C. verum* extract varied according to the type of extract, concentration, and time period. Statistical analysis revealed significant differences at the 0.05 probability level, with the LSD value being 1.149 for the extract type, 1.3268 for the concentrations, and 1.3268 for the time periods. The three-way interaction value between the extract type, concentration, and time period was 4.596, indicating that the effectiveness of cinnamon extract was not dependent on a single factor but rather influenced by the interaction of all the studied factors.

The overall means indicate that the alcoholic extract was the most effective at repelling ants, with an average repelling rate of 75.89%, followed by the boiled aqueous extract at 73.29%, and then the cold aqueous extract at 71.18%. On the other hand, the results showed a clear positive correlation between the extract concentration and its repellent efficiency. The average repellency rate gradually increased from 63.72% at a 5% concentration to 70.25% at 10%, then to 75.69% at 15%, reaching a peak of 84.16% at 20%. Regarding time intervals, the highest average repellency rate was observed after 10 minutes, reaching 77.83%. This then gradually decreased to 75.52% after 30 minutes, 72.05% after one hour, and finally to 68.41% after 24 hours. Analysis of the interaction between the studied factors revealed that the optimal treatment was the 20% alcoholic extract applied after 10 minutes, achieving the highest repellency rate of 91.33%. Conversely, the lowest repellency rate was recorded with the 5% cold aqueous extract after 24 hours, at 54.66%.

Effect of A. cepa extracts on ant repelling and attracting

Table 4 data indicates that the type of extract, concentration, and time period had a significant effect on the ant repelling and attracting rates. Statistical analysis at a probability level of 0.05 showed significant differences between treatments. The LSD value for the extract type was 0.4787, and for both concentration and time period, it was 0.5528. The three-way interaction value between the factors was 1.9148, confirming that the ants' response to the onion extract was influenced by the interaction of all these factors.

The results showed that the alcoholic extract achieved the highest average repelling rate of 64.95%, compared to the boiled aqueous extract at 62.22%, and the cold aqueous extract at the lowest average repelling rate of 59.83%. This is attributed to the alcohol's ability to extract a larger percentage of the active sulfur compounds present in *A. cepa*, which possess repellent activity that affects the ants' chemical receptors and reduces their attraction to the extract source. The results also showed that the repelling efficiency increased with increasing extract concentration. The average repelling rate rose from 57.11% at a 5% concentration to 69.33% at a 20% concentration, indicating that increasing the concentration of the active compounds enhances their ability to influence the chemical behavior of ants and reduce their approach to the treatment source. Regarding the time period, the highest repelling rate was

Table 3. Effectiveness of *C. verum* extracts in repelling and attracting ants

Extract Type	Conce	Repellency ratio					Attraction ratio				
		Time period				Average Extract effect	Time period				Average Extract effect
		After 10 min	After 30 min	After An hour	After 24h		After 10 min	After 30 min	After An hour	After 24h	
Alcoholic	5%	70.33	68.33	66.00	61.00	75.97	29.66	31.66	34.00	39.00	24.08
	10%	77.33	74.33	70.33	64.33		22.66	25.66	29.66	32.33	
	15%	82.66	82.00	77.00	73.66		17.33	19.33	23.00	26.33	
	20%	91.33	88.66	85.66	82.66		8.66	11.33	14.33	17.33	
Boiling water	5%	67.66	65.33	62.66	59.00	73.29	32.33	34.66	37.33	41.00	26.70
	10%	73.33	72.00	69.33	66.33		26.66	28.00	30.66	33.66	
	15%	79.00	77.66	72.00	70.33		21.00	22.33	28.00	29.66	
	20%	89.00	86.33	82.66	80.00		11.00	13.66	17.33	20.00	
Cold water	5%	66.00	63.66	59.00	54.66	71.18	33.00	36.33	41.00	48.66	29.02
	10%	73.66	71.00	67.00	64.00		26.33	29.00	33.00	36.00	
	15%	77.66	76.33	73.00	68.33		22.33	23.66	27.00	31.66	
	20%	85.00	82.00	80.00	76.66		15.00	18.00	20.00	23.00	
Time effect rate		77.83	75.52	72.05	68.41		22.16	24.47	27.94	31.58	
Concentration effect rate		5%	10%	15%	20%		5%		10%	15%	20%
		63.72	70.25	75.69	84.16		36.55		29.72	24.30	15.83
L.S.D 0.05		Extract Type	Conce	Time period	Extract × Conc. × Time		Extract Type		Conce	Time period	Extract × Conc. × Time
		1.149	1.3268	1.3268	4.596		1.224		1.4133	1.4133	4.8958

Table 4. Effectiveness of *A. cepa* extracts in repelling and attracting ants

Extract Type	Conce	Repellency ratio					Attraction ratio				
		Time period				Average Extract effect	Time period				Average Extract effect
		After 10 min	After 30 min	After An hour	After 24h		After 10 min	After 30 min	After An hour	After 24h	
Alcoholic	5%	63.00	61.33	58.00	55.33	64.95	37.00	38.66	42.00	44.66	35.04
	10%	66.66	64.33	61.00	58.00		33.33	35.66	39.00	42.00	
	15%	69.00	66.66	65.00	61.00		31.00	33.33	35.00	39.00	
	20%	76.33	74.33	71.33	68.00		23.66	25.66	28.66	32.00	
Boiling Water	5%	61.00	60.33	56.00	52.33	62.22	39.00	39.66	44.00	47.66	37.77
	10%	63.33	60.00	57.33	54.66		36.66	40.00	42.66	45.33	
	15%	67.00	65.00	62.00	59.00		33.00	35.00	38.00	41.00	
	20%	73.00	71.00	68.66	65.00		27.00	29.00	31.33	35.00	
Cold Water	5%	59.00	55.66	52.66	50.66	59.83	42.00	44.33	47.33	49.33	40.16
	10%	61.33	59.66	56.00	53.66		38.66	40.33	44.00	46.33	
	15%	65.33	64.66	59.33	55.00		34.66	35.33	40.66	45.00	
	20%	70.33	68.00	65.00	61.00		29.66	32.00	35.00	39.00	
Time effect rate		66.27	64.25	61.02	57.80		33.72	35.75	38.97	42.19	
Concentration effect rate		5%	10%	15%	20%			5%	10%	15%	20%
		57.11	59.66	63.25	69.33			42.88	40.33	36.75	30.66
L.S.D 0.05		Extract Type	Conce	Time period	Extract × Conc. × Time			Extract Type	Conce	Time period	Extract × Conc. × Time
		0.4787	0.5528	0.5528	1.9148			0.4787	0.5528	0.5528	1.9148

recorded within 10 minutes (66.27%), then gradually decreased to 57.80% after 24 hours. This is likely due to the decrease in the concentration of volatile compounds as a result of evaporation or decomposition over time, thus reducing their repelling efficiency.

The interaction between the factors showed that the 20% alcoholic extract achieved the best repelling response after 10 minutes (76.33%), while the 5% cold aqueous extract recorded the lowest repelling rate after 24 hours (50.66%). This demonstrates that achieving the highest effectiveness requires using a high concentration of the alcoholic extract during the initial exposure period. Conversely, the attraction rates followed the opposite trend. The alcoholic extract recorded the lowest average attraction rate at 35.04%, while the cold aqueous extract recorded the highest average at 40.16%. The attraction rate also decreased from 42.88% at a 5% concentration to 30.66% at a 20% concentration. The lowest attraction rate of 23.66% was recorded after 10 minutes using the 20% alcoholic extract, while the highest attraction rate of 49.33% was recorded after 24 hours using the 5% cold aqueous extract. This confirms an inverse relationship between the repulsion and attraction rates. Overall, it appears that the 20% alcoholic onion extract was the most efficient in achieving the highest repulsion rate and the lowest attraction rate during the first 10 minutes.

Comparison of plant extracts and efficacy in the study

Table 5 reveals significant differences in the studied plants' ability to repel and attract ants. Statistical analysis at a probability level of 0.05 showed that the LSD value for the plants was 1.1522, and for the time period, it was 1.0306. The interaction value between the plant and the time period was 2.3044, indicating that the efficacy of the plant extracts varied according to the plant species and the duration of exposure.

The results showed that *S. aromaticum* was the most effective plant for repelling ants, with an average repellent rate of 94.25%, followed by *C. verum* at 87.08%, while *A. cepa* recorded the lowest repellent rate at 72.50%. The results also showed that the time period had a clear effect on the effectiveness of the extracts. The highest repellent rate was recorded after 10 minutes, averaging 84.46%, then gradually decreased to 83.46% after 30 minutes, 80.80% after one hour, and finally to 78.06% after 24 hours.

In contrast, the attraction rates showed the opposite trend to the repellent rates. Clove recorded the lowest average attraction rate at 5.75%, followed by cinnamon (12.91%), while onion recorded the highest average attraction rate at 27.50%. The attraction rates also increased gradually with increasing exposure time, reaching 13.53% after 10 minutes and rising to 21.93% after 24 hours.

Discussion

Results of the current study showed that the studied plant extracts, namely *C. verum*, *S. aromaticum* and *A. cepa*, have a clear effect on ant behavior. The attraction and repulsion ratios differed significantly according to the type of plant used, the type of extract, the concentration, and the duration of exposure. In addition, there were significant effects of interactions between these factors. These results indicate that the repulsive effectiveness of the studied plant extracts does not depend on a single factor, but rather represents the result of the interaction of a group of factors related to the chemical composition of the plant, the nature of the active compounds, the efficiency of the solvent used in their extraction, their concentration, and the duration of their presence in the surrounding environment. These results are consistent with earlier reports indicating that the effectiveness of plant pesticides depends largely on the type of active compounds and the duration of exposure to them (5). This aligns with earlier findings stating that the biological activity of plant extracts varies depending on the chemical diversity among plants, particularly their content of volatile oils, phenolic compounds, and terpenes (7). The study's results confirm that using multiple plants and comparing different extraction methods provides a more accurate picture of repellent activity. While plants may possess active compounds, the extraction method must be suitable for extracting those compounds. By comparing the types of extracts, the results showed that the alcoholic extract was more effective at repelling ants than the aqueous extract (boiled and cooled) for all studied plants. This superiority indicates that the type of solvent played a significant role in determining the efficiency of plant extracts. This is attributed to alcohol's ability to penetrate plant tissues and extract a wider range of active organic compounds, including aromatic compounds, volatile oils, and phenolic compounds, compared to water. Boiling likely leads to the loss of some volatile compounds due to heat exposure, which explains why the boiled aqueous extract was intermediate between the alcoholic and the cold aqueous extracts. This is consistent with earlier reports explaining that plant extracts rich in volatile oils are more effective when extracted with organic solvents, and that their efficiency increases with increasing concentration, while their effectiveness gradually decreases over time as a result of the loss of some of the volatile compounds (6,19).

Table 5. Comparison of the efficiency of the plant extracts

Plants	Repellency ratio					Attraction ratio				
	Time period				Plant effect Rate	Time period				Plant effect rate
	After 10 min	After 30 min	After An hour	After 24h		After 10 min	After 30 min	After An hour	After 24h	
S. aromaticum	98.66	95.00	92.33	91.00	94.25	1.33	5.00	7.66	9.00	5.75
C.verum	91.33	88.66	85.66	82.66	87.08	8.66	11.33	14.33	17.33	12.91
A. cepa	76.33	74.33	71.33	68.00	72.50	23.66	25.66	28.66	32.00	27.50
Time effect rate	84.46	83.46	80.80	78.06		13.53	16.53	19.20	21.93	
L.S.D 0.05			Plants				Time period		Plants × Time period	
			1.1522				1.0306		2.3044	

When studying the effect of concentration, the results showed an increase in repelling efficiency with increasing concentration of the extracts. A 20% concentration was the most effective, while a 5% concentration was the least effective in repelling rates. This is attributed to the fact that increasing the concentration leads to an increase in the amount of active compounds present per unit volume and treated area, thus increasing the intensity of the chemical signals to which the ants are exposed. These compounds affect the ants' behavior by causing aversion to the scent source or altering their response to the treated area. This result is consistent with an earlier report stating that the biological activity of plant extracts is often related to the amount of active ingredients in the extract, as increasing the concentration can lead to an increased effect (19). A study on the effectiveness of *S. aromaticum* and its bioactive compounds against another arthropod supported the existence of a clear effect of the main compound in *S. aromaticum*, eugenol, which is among the most effective compounds in affecting the target organism (20). The results of the study also showed that increasing the concentration not only led to an increase in the repelling rate but also a decrease in the attraction rate. The alcoholic extract recorded the lowest attraction rate, while the cold aqueous extract recorded the highest. This demonstrates an inverse relationship between repulsion and attraction with respect to the treatment source. Regarding the effect of exposure duration, the results showed that the highest average repellent rate was recorded after 10 minutes, then it gradually decreased to 30 minutes, then to one hour, and then to 24 hours. In contrast, the attractant rate increased from 10 minutes to 24 hours. This can be explained by the decrease in the concentration of volatile compounds in the surrounding medium as a result of evaporation, diffusion, or decomposition, which leads to a decrease in the intensity of the chemical stimulus responsible for the repellency. The result is consistent with earlier findings that many oils and compounds are characterized by a rapid effect of limited duration (5), and with reports stating that the effectiveness of plant oils is at its highest levels during the first hours of use, then begins to decrease gradually as a result of the loss of volatile compounds (21). When comparing the studied plants, *S. aromaticum* was the most effective at repelling ants, recording the highest average ant repellency and the lowest average ant attraction, followed by *C. verum* and then *A. cepa*. This variation indicates differences in the chemical composition of the plant extracts and the nature of the compounds they contain. This result is consistent with earlier reports stating that plants rich in volatile oils, particularly those containing phenolic compounds, possess higher repellent activity against many insects (7,22). The apparent superiority of *S. aromaticum* may be related to its eugenol content, one of the active compounds in clove, which possesses biological and behavioral properties that enable it to affect insects and arthropods. This study is consistent with earlier work on the repellency of clove and its constituents against insect pests (23,24). *C. verum* came in second in terms of the repellent effect of its alcoholic extract. This effect is attributed to the alcohol's ability to extract a larger quantity of active compounds, especially cinnamaldehyde, which is the main compound in cinnamon responsible for its repellent effect (25). Earlier work confirmed that cinnamaldehyde possesses high biological activity against many insects, affecting their sensory receptors and causing them to avoid the scent source, and that it is among the most effective plant compounds for influencing insect behavior (26).

It appears that a 20% alcoholic extract of onion, applied within the first 10 minutes, was the most effective in achieving the highest repellent and lowest attractant rates. This is attributed to the presence of volatile sulfur compounds in *A. cepa*, such as thiosulfinates and their derivatives, which affect the chemical receptors of insects and reduce their attraction. This finding is consistent with earlier work demonstrating that organosulfur compounds in *Allium* plants possess biological, insecticidal and repellent activity against several insects (27), and with reports indicating that organosulfur compounds in onions are the primary agents responsible for their biological activity and repellent effects (28-33).

Overall, the results confirm that plant extracts possess a clear ability to modify ant behavior, and that their efficacy varies depending on the concentration, plant species, extraction method, and exposure duration. The alcoholic extract of cloves may represent a promising source for developing natural ant repellents. However, further chemical, toxicological, and applied studies are necessary to identify the compounds responsible for the effect and to assess their potential use within integrated pest management programs.

Conclusion

The response of ants varied according to the type of plant, type of extract, concentration, and duration of exposure. The alcoholic extract was more effective compared to the aqueous extract, and *S. aromaticum* was the most effective plant in repelling ants, which confirms the possibility of using plant extracts, especially *S. aromaticum*, as promising natural alternatives to traditional chemical pesticides in reducing the spread of ants.

Acknowledgements

The authors are grateful to the Department of Biology, College of Education for Pure Sciences, University of Karbala, for providing the laboratory facilities that made this work possible.

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Conflict of Interests

The authors declare that they have no conflict of interests.

Data Availability Statement

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Ethical Approval

This study did not involve human participants or vertebrate animals. All experiments were performed on an invertebrate insect species (*Solenopsis invicta*), for which ethical approval is not required under the applicable national and institutional regulations. The work was carried out in the laboratories of the Department of Biology, College of Education for Pure Sciences, University of Karbala, in accordance with institutional biosafety and laboratory practice regulations.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. It was funded entirely by the authors.

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