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Efficiency of Eucalyptus Oil Nanocapsule (*Eucalyptus* sp.) in Controlling the Whitefly, *Bemisia tabaci* on Sweet Pepper in the Greenhouse

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ABSTRACT

The study investigated the efficacy of nanocapsules and normal oil of eucalyptus to control the whitefly *Bemisia tabaci* population that infested two sweet pepper, *Capsicum annuum* (Charisma and Sierra Nevada), varieties. Data revealed that eucalyptus oil in all its forms could decrease the eggs, nymphs, and adults numbers of *B. tabaci*, on both sweet pepper varieties. Among others, the 5% nanocapsule treatment scored the highest mortality rate after the pesticide Actara at all the insect stages. In addition, nanocapsules prepared from extracted eucalyptus oil scored the best control compared to nanocapsules of commercial oil or extracted eucalyptus oil treatments at all insect stages. For the Charisma variety, this treatment scored highest, with 94.87%, 97.45%, and 93.27% kill efficiency percentage (KE%) in whitefly eggs, nymphs, and adult stages after 4, 7, and 2 days of treatments, respectively. While the pesticide Actara scored 100% KE at all whitefly stages. Similarly, the extracted oil nanocapsule treatment was the best among other treatments in reducing the percentage of *B. tabaci* on the Sierra Nevada variety. The highest KE percentages of whitefly eggs, nymphs, and adults were 96.92%, 97.84%, and 91.79% after 7, 4, and 1 days of treatment, compared to the pesticide Actara, which achieved the highest 100% KE at all whitefly stages. Thus, nanocapsules of commercial oil can be a promising eco-friendly formulation alternative to insecticides against *B. tabaci*.

1 | Introduction

The genus, *Capsicum* spp., is one of the most important and widely grown genera worldwide, as a vegetable and a spice crop. Native to tropical regions, it has since spread globally. This genus includes more than 30 species; among those are *C. annuum*, *C. frutescens*, *C. chinense*, *C. baccatum*, and *C. pubescens* [1]. Sweet pepper (*Capsicum annuum* L.) is the most widespread worldwide. In Iraq, the approximated sweet pepper cultivation area was 2118 hectares with an estimated total fruit production of 46,498 tons [2]. Sweet pepper fruits have a high

nutritional value, as they contain high vitamins, including vitamin C, antioxidants, anticoagulants, and other healthy compounds [3, 4]. This crop production can be limited by several insect pests, including whiteflies, thrips, aphids, tomato fruit borers, pepper fruit flies, and others [5].

In recent years, the whitefly, *B. tabaci* has emerged as a key pest threatening sweet pepper cultivation along with many crops. As a polyphagous insect, it is known to infest more than 70 crops around the world [6, 7]. The whitefly is a small, soft-bodied insect belonging to the family Aleyrodidae within the order Hemiptera [8]. Nymphs

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and adults of whitefly can damage pepper plants through feeding on plant sap, mainly on the lower surface of the leaves, resulting in deformation, small blade size, and stunting of the leaves [9, 10]. In case of severe infestation, plants may suffer weakness, yellowing, and death. More damage may occur through producing a honeydew, which covers the plant parts, providing a suitable environment for fungal growth. Moreover, whitefly can transmit viral diseases to plants. The whitefly can develop a resistance against different groups of pesticides, including organophosphates, carbamates, pyrethroids, chlorinated hydrocarbons, and insect growth regulators (IGRs) [11]. Naveen et al. [12] indicated that whiteflies' resistance to pesticides is related to the excessive use of many pesticides, the short generation time of this insect, high fecundity, and the rapid movement of adults.

Many plants, including *Eucalyptus* spp., can be a source of biological compounds that have insecticidal activities, leaving no toxic residues in the soil and water [13–15]. Iqbal et al. [16] indicated that plant oils could suppress *B. tabaci* populations significantly on okra plants and the okra pods found in plots sprayed without any toxic effects the day after spraying, compared to chemical pesticides. Similarly, Mondal et al. [17] showed that eucalyptus oil caused insignificant whitefly mortality, ranging from 21.56% to 84.90% and 23.42% to 86.21% at concentrations of 0.07% and 0.9% after 24 and 48 h of exposure, respectively.

In terms of their properties, essential oils are characterized by chemical instability in the presence of light, humidity, air, and high temperatures, resulting in decomposition of their active substances. However, when essential oils are coated with nanomaterials like polyethylene glycol (PEG) polymer, their release can be controlled, preventing rapid evaporation. Moreover, stability and effectiveness against pests at low doses are enhanced [18, 19]. Oil extracted from the *Zanthoxylum rhoifolium* plant encapsulated in a nanoformat could decrease the numbers of whitefly individuals up to 95% at all stages, suggesting such formulations can be applied in integrated pest management [20]. Therefore, the present study aimed to investigate the insecticidal activity of the nanocapsule of eucalyptus oil against whitefly in the greenhouse.

2 | Materials and Methods

2.1 | Eucalyptus Leaf Preparation and Oil Extraction

Leaves collected from eucalyptus trees were washed thoroughly and dried at room temperature. Ten days later, the dried leaves were ground using an electric grinder with a sieve size of 30–40 mesh, and the powder was put in a glass bottle up to oil extraction. Eucalyptus oil extraction was carried out in the plant extracts laboratory in the Agricultural Research Office in Abu Ghraib, through water vapor distillation using a Clevenger device. About 25–30 g of eucalyptus leaf powder were placed in the device container, mixed with 250–300 mL of distilled water, and incubated for 3–4 h at 90–100°C. The extraction process was repeated several times for oil concentration and purity. The final oil volume was about 0.8 mL at a concentration of 100% per 30 g of eucalyptus leaf powder. The resultant eucalyptus oil was kept in a tight glass bottle, wrapped in opaque paper, and kept at a 3–5°C until use [21].

2.2 | Commercial Eucalyptus Oil and the Pesticide Actara

Pure (100%) eucalyptus (*E. globulus*) oil was provided by Healing Solution Company (www.healingsolution.com). The pesticide Actara 25 WG (Thiamethoxam 250 g/kg) was purchased from Syngenta, Austria (recommended dose of 200 g/hectare).

2.3 | Preparation of Eucalyptus Oil Nanocapsules

Eucalyptus oil nanocapsules were prepared by grinding 1 g of PEG 50%, and the powder was placed in a thermal glass flask and melted to 65°C. 5 mL of eucalyptus oil was added gradually mixed for 90 min using a hot platen stirrer [22]. Similarly, nanocapsules were prepared from the commercial eucalyptus oil.

2.4 | Preparing the Eucalyptus Oil Liquid Concentrations

Three concentrations of each eucalyptus oil extracted, commercial and the nanocapsules, were prepared. 1 mL, 2.5 mL, or 5 mL of each oil formulation was mixed with 1 mL of Dimethyl Sulfoxide (DMSO) solution in a 250 mL volumetric flask. The final volume was adjusted to 100 mL by adding tap water to obtain 1% and for 2.5% and 5%, respectively. The selection of the concentrations of 1%, 2.5%, and 5% of the treatments was based on previous studies [15, 23]

2.5 | Greenhouse Experiments

The experiment was carried out in a 9 × 25 m protected house during the spring season of 2023. Pepper plants (5–6 leaf stage) of the two Spanish varieties, Charisma and Sierra Nevada (chosen for their common cultivation by farmers in Iraq), were planted. The experimental field (greenhouse) was divided into four terraces, 90 cm wide and 30 cm high. The terraces were covered with a plastic mulch to prevent weed growth and reduce water evaporation from the soil. Pepper plants were transplanted in the first week of March, at 40 cm space intervals between plants. A drip irrigation system was applied. Service operations recommended for each variety were followed. Pepper plants were left for natural whitefly infestation.

The experiment was designed with a Randomized Complete Block Design (RCBD) [24]. Six treatments, including commercial, extracted, and nanocapsules of each eucalyptus oil; Actara insecticide; and control with three replicates (10 plants for each replicate) and for each pepper variety (Charisma and Sierra Nevada), were performed. After whitefly infestation on sweet pepper plants, the plants were sprayed with each treatment at three concentrations, 1%, 2.5%, and 5%, using a 16-L backpack sprayer. The control treatment was sprayed with water only, and the spraying included the whole plant, focusing on the lower surface of the leaves. To avoid the exposing of adjacent replicates during spraying, a barrier of reinforced cardboard was placed. The inhibition percent of whitefly eggs and mortality of nymphs and adults were calculated 1, 2, 3, 4, 5, 6, 7, 14, and 21 days after treatments. Three plants were randomly selected from each replicate, and three leaf samples from different levels of each plant were selected randomly (the sample size was 9 leaves for each treatment), treated and varied separately and placed in

transparent, tightly sealed polyethylene bags. Each bag was labeled with the information, including sampling date, treatment, pepper variety, and the duplicate number. Samples were examined using a Hamburg light microscope at 4× magnification power. The total number of eggs, nymphs, and adults was counted, and the inhibition of eggs was considered when they were not hatched, and the movement of mobile insect stages was checked with a soft brush to confirm dead individuals.

The efficiency of the oils, oil nanocapsules, and pesticide was calculated based on mortality percentage and converted to kill efficiency by applying the equation of Henderson and Tilton [25] as follows:

$$\text{Kill Efficiency\% (KE\%)} = 1 - \left[\frac{\text{Cb} \times \text{Ta}}{\text{Ca} \times \text{Tb}} \right] \times 100,$$

where, Cb=Average number of Insects per plant in control before spray. Ta = Average number of insects per plant in treatment plots after spraying. Tb=Average number of Insects per plant in treatment plots before spray. Ca=Average number of Insects per plant in control after spray.

2.6 | Statistical Analysis

Data were subjected to analysis of variance (ANOVA) and analyzed using a RCBD, and a comparison between means was made at $p \leq 0.05$. using least significant difference (LSD). SAS 2001 software was used for data statistical analysis.

3 | Results and Discussions

3.1 | The Efficiency of the Eucalyptus Oil Nanocapsule in Controlling the Whitefly *B. tabaci* on Sweet Pepper

3.1.1 | The Efficiency of Eucalyptus Oil Nanocapsule in Controlling the Whitefly *B. tabaci* on Charisma Variety

3.1.1.1 | The Effect of Eucalyptus Oil Nanocapsule on the Eggs of the Whitefly *B. tabaci* on Charisma Variety. Data obtained from greenhouse treatments indicated that the nanocapsule of extracted eucalyptus oil was the best in inhibiting the hatching of eggs on the Charisma variety (Table 1). This treatment scored highest at 94.87 (KE%) at 5% after 4 days of treatment, followed by nanocapsules of commercial oil at the same period and concentration, scoring 94.17 (KE%). In contrast, eucalyptus oil from a commercial source scored the highest at 91.03% after 3 days of treatment at a concentration of 5% compared to 85.99% KE after 3 days of extracted oil treatment. Whilst the pesticide Actara treatment scored 100% KE after 14 days of treatment.

3.1.1.2 | The Effect of Eucalyptus Oil Nanocapsule on the Whitefly *B. tabaci* Nymphs on Charisma Variety. Extracted eucalyptus oil nanocapsule treatment at 5% concentration showed a high KE percent in insect nymphs, scoring 97.45% after 7 days of treatment (Table 2). Whereas the commercial oil nanocapsule scored the 2nd highest 95.83% KE at 5 days of treatment, at the same concentration. While KE of 100% was recorded in the pesticide Actara after 14 days of treatment.

TABLE 1 | Effect of eucalyptus oil nanocapsules on eggs of the whitefly *B. tabaci* on the charisma variety.

Treatments	Conc. (%)	KE (%)									Avg.
		Days after spray									
		1	2	3	4	5	6	7	14	21	
Actara	200 g/ha	26.39	41.06	56.63	71.86	82.78	86.74	92.77	100.00	100.00	73.14
Extracted eucalyptus oil	1	29.33	31.89	34.85	40.98	38.17	30.63	30.56	29.75	23.48	32.18
	2.5	32.31	55.64	63.18	67.67	53.54	50.19	41.21	34.14	28.22	47.34
	5	58.68	76.00	85.99	78.82	72.91	69.98	54.58	41.99	33.31	63.58
Extracted eucalyptus oil nanocapsule	1	18.68	17.70	19.71	27.04	30.62	23.44	18.97	18.92	10.78	20.65
	2.5	28.75	35.13	55.67	67.84	63.69	54.99	50.82	41.42	33.61	47.99
	5	13.97	24.08	54.95	94.87	91.83	75.24	63.80	38.78	24.36	53.54
Commercial eucalyptus oil	1	19.58	20.00	20.80	29.82	22.85	22.76	19.97	14.57	6.39	19.64
	2.5	31.08	31.43	44.85	48.04	51.63	47.21	40.83	34.13	28.88	39.79
	5	43.46	71.82	91.03	88.45	86.06	75.94	60.79	38.57	26.19	64.70
Commercial eucalyptus oil nanocapsule	1	17.19	23.79	24.70	25.08	33.19	27.23	23.63	22.67	11.67	23.24
	2.5	21.51	33.58	48.44	66.71	63.02	59.31	53.47	24.68	12.68	42.60
	5	21.88	67.92	93.87	94.17	89.25	89.29	84.27	49.93	30.88	69.05
LSD 5%		NS									

TABLE 2 | Effect of eucalyptus oil nanocapsules on *B. tabaci* nymphs on the Charisma variety.

Treatments	Conc. (%)	KE (%)									
		Days after spray									
		1	2	3	4	5	6	7	14	21	Avg.
Actara	200 g/ha	21.48f	38.78e	54.11d	74.48b	87.17a	92.54a	96.87a	100.00a	100.00a	73.94b
Extracted eucalyptus oil	1	19.41ef	21.85f	22.27f	23.91f	23.49f	27.62e	23.27f	15.90f	15.41f	21.46f
	2.5	20.99f	27.90e	27.94e	39.34e	45.75d	43.35d	33.82e	17.26f	12.48f	29.87e
	5	43.90d	52.86d	59.37c	65.75c	51.48d	44.43d	35.80e	30.27e	19.13f	44.78d
Extracted eucalyptus oil nanocapsule	1	19.41f	23.27f	23.91f	27.62e	23.49f	22.27f	21.85f	15.90f	15.48f	21.47f
	2.5	12.48f	27.90e	39.34e	45.75d	43.35d	33.82e	27.94e	20.99	17.26	29.87
	5	19.27f	31.95e	55.84d	64.94c	82.96b	94.16a	97.45a	30.36e	21.90f	55.43d
Commercial eucalyptus oil	1	20.38f	27.53e	30.00e	35.99e	27.27e	26.66e	21.27f	15.12f	15.07f	24.37f
	2.5	43.78d	48.00d	56.38c	64.73c	72.59b	70.37c	59.50c	40.73d	31.31e	54.15d
	5	56.75c	73.77c	78.55b	87.54a	90.93a	85.74b	78.28c	45.19d	23.63f	68.93c
Commercial eucalyptus oil nanocapsule	1	16.66f	21.27f	27.78e	28.06e	27.09e	26.66e	20.56f	19.08f	17.65f	22.76f
	2.5	22.86f	43.47d	54.53d	62.93c	77.57b	77.27b	73.84b	32.32e	31.17e	52.88d
	5	67.41c	78.99b	86.38a	91.01a	95.83a	91.15a	85.75b	55.73d	26.12e	75.37c
LSD 5%		15.19									

Note: The symbols “a,” “b,” “c,” “d,” “e,” and “f” denote the levels of statistical significance, indicating meaningful differences between the groups.

3.1.1.3 | The Effect of Eucalyptus Oil Nanocapsule on Adults of the Whitefly *B. tabaci* on Charisma Variety.

Extracted eucalyptus oil nanocapsules at a concentration of 5% had the highest impact on whitefly adults infesting the Charisma variety when the highest KE, 93.27%, was recorded after 2 days of treatment (Table 3). Whereas at the same concentration, the nanocapsule of the commercial oil, KE, was 87.44% after 1 day of treatment. While the pesticide Actara showed the highest KE activity on whitefly adults after 7 days of treatment, where scored 100%.

3.2 | Efficiency of Eucalyptus Oil Nanocapsule in Controlling the Whitefly *B. tabaci* on Sierra Nevada Variety

3.2.1 | The Effect of Eucalyptus Oil Nanocapsules on the Eggs of the Whitefly *B. tabaci* on Sierra Nevada Variety

Nanocapsules of extracted eucalyptus oil could decrease the number of whitefly eggs on the Sierra Nevada variety, but not significantly (Table 4). At 5% concentration, this treatment scored a maximum KE of 96.92% 7 days after treatment, followed by the commercial eucalyptus oil nanocapsule, which scored 95.15% KE after 5 days of treatment. While the highest effect of the pesticide Actara on insect eggs was 100% 14 days after treatment.

3.2.2 | The Effect of Eucalyptus Oil Nanocapsule on *B. tabaci* Whitefly Nymphs on Sierra Nevada Variety

A significant decrease in the number of whitefly nymphs was observed in the nanocapsule of both extracted and commercial eucalyptus oil treatments on the Sierra Nevada variety (Table 5). Those nanocapsule treatments scored a maximum KE of 97.84%

and 95.57% after 4 days of treatment at a concentration of 5%, respectively. While the pesticide Actara had a 100% lethal effect after 14 and 21 days of treatment.

3.2.3 | The Effect of Eucalyptus Oil Nanocapsule on Adults of the Whitefly *B. tabaci* on the Sierra Nevada Variety

At a concentration of 5%, a significant KE on whitefly adults was observed in the extracted eucalyptus oil nanocapsule treatments, which scored the highest at 91.79%, followed by the nanocapsules of the commercial oil, which scored 87.42%, after 1 day of treatment (Table 6). In contrast, the pesticide Actara scored 100% KE on whitefly adults after 7 days.

The above data suggests that the nanocapsule of extracted and commercial eucalyptus oil showed higher insecticidal activity compared to their normal oil formulation, at the same concentrations. This may be related to the nanoparticle size of eucalyptus oil, which enables easier penetration into insect bodies and plant uptake. Similarly, Prabhu et al. [26] concluded that the nanoextract of eucalyptus oil used to prepare the nanoparticles is rich in chemical compounds and serves as a stabilizing, reducing, and encapsulating material. Therefore, nano-oils are among newly adopted approaches used to control whitefly species [27].

Data also showed that the use of eucalyptus oil in its various concentrations has an effect in reducing the numbers of eggs, nymphs, and adults of the whitefly. However, there is a difference in the reduction percentage, which can be attributed to a direct relationship between the concentration and its effect. The high insecticidal activity of eucalyptus extract on the insect may be related to the increase in the plant's active substance present in the extract [27, 28]. Moreover, the difference in reduction

TABLE 3 | Effect of eucalyptus oil nanocapsules on adults of the whitefly *B. tabaci* on the charisma variety.

Treatments	Conc. (%)	KE (%)									Avg.
		Days after spray									
		1	2	3	4	5	6	7	14	21	
Actara	200 g/ha	32.90	48.81	63.29	77.77	91.72	93.35	100.00	96.73	86.92	76.83
Extracted eucalyptus oil	1	42.75	38.12	34.95	33.13	32.73	29.82	21.01	27.92	17.37	30.87
	2.5	54.99	48.55	41.97	45.08	44.53	37.89	28.79	26.79	15.89	38.28
	5	56.09	53.38	52.16	50.63	45.93	45.19	41.48	37.04	33.43	46.15
Extracted eucalyptus oil nanocapsule	1	42.75	38.12	34.95	33.13	32.73	29.82	27.92	21.01	17.37	30.87
	2.5	58.30	51.66	45.78	48.89	48.34	42.67	33.29	31.55	22.06	42.50
	5	82.61	93.27	81.06	74.14	65.85	47.42	36.97	32.40	26.06	59.98
Commercial eucalyptus oil	1	46.45	41.76	36.24	31.37	34.36	31.09	29.37	25.13	24.76	33.39
	2.5	43.45	44.97	46.07	44.20	44.77	41.95	37.28	37.63	31.16	41.28
	5	77.49	82.30	76.91	72.56	70.57	63.14	54.67	53.74	43.25	66.07
Commercial eucalyptus oil nanocapsule	1	41.58	41.16	33.80	30.36	33.59	31.11	30.47	23.37	20.48	31.77
	2.5	46.59	42.22	43.76	44.29	43.49	41.55	34.78	32.01	29.02	39.75
	5	87.44	82.17	81.43	81.57	79.26	76.26	71.13	56.60	48.00	73.76
LSD 5%		NS									

TABLE 4 | Effect of eucalyptus oil nanocapsules on eggs of the whitefly *B. tabaci* on the Sierra Nevada variety.

		KE (%)									
Treatments	Conc. (%)	Days after spray									Avg.
		1	2	3	4	5	6	7	14	21	
Actara	200 g/ha	29.50	42.53	60.98	74.32	85.74	86.38	92.92	100.00	100.00	74.71
Extracted eucalyptus oil	1	15.17	15.36	18.01	20.29	22.80	28.89	21,75	14.66	13.99	18.65
	2.5	24.91	25.80	37.29	57.75	60.44	44.71	36.89	24.07	20.17	36.89
	5	42.35	48.36	60.56	74.04	80.61	73.21	69.90	27.98	23.19	55.58
Extracted eucalyptus oil nanocapsules	1	18.85	19.61	20.74	21.59	26.81	28.46	21.78	18.85	18.34	21.67
	2.5	44.54	52.19	59.78	62.24	72.37	72.08	64.39	44.75	40.59	56.99
	5	49.65	58.86	69.91	75.19	87.40	94.35	96.92	42.73	40.95	68.44
Commercial eucalyptus oil	1	23.54	23.47	23.66	25.63	33.09	24.24	24.60	20.63	19.60	24.27
	2.5	24.89	28.51	41.13	43.35	47.13	44.53	35.33	26.09	23.26	34.91
	5	39.57	59.84	77.71	88.28	91.86	87.91	73.32	45.23	24.57	65.37
Commercial eucalyptus oil nanocapsules	1	21.86	21.38	23.44	23.44	31.33	22.28	20.55	17.80	15.36	21.94
	2.5	23.85	27.62	41.64	47.25	59.44	57.52	43.87	18.64	16.59	37.38
	5	58.33	72.75	87.58	90.02	95.15	94.60	90.50	37.94	26.72	72.62
LSD 5%		NS									

percentage in whitefly eggs can be attributed to the effect of plant extracts on the number of individuals emerging. Those plant extracts release volatile compounds, which may penetrate

the egg through the hilar opening or eggshell, resulting in the death of the embryo or incomplete development. The oil may act as a restriction that limits or prevents the entry of oxygen to

TABLE 5 | Effect of eucalyptus oil nanocapsules on the whitefly *B. tabaci* nymphs on the Sierra Nevada variety.

		KE (%)									
Treatments	Conc. (%)	Days after spray									Avg.
		1	2	3	4	5	6	7	14	21	
Actara	200 g/ha	25.38f	42.17e	59.50d	80.86b	89.05a	95.70a	97.79a	100.00a	100.00a	76.72b
Extracted eucalyptus oil	1	28.15f	28.59f	33.04f	34.00f	32.58f	32.09f	30.35f	25.14f	23.16f	29.68f
	2.5	27.36f	29.45f	46.67e	49.39d	39.99e	36.73e	31.57f	24.77f	18.91g	33.87f
	5	38.35e	41.19e	43.04e	62.84c	56.25d	48.61d	45.98e	23.57f	14.93g	41.64e
Extracted eucalyptus oil nanocapsules	1	20.28g	28.63f	29.82f	30.00f	29.98f	29.39f	27.83f	25.78f	20.12g	26.87f
	2.5	17.78g	20.69g	31.94f	44.58e	47.40e	42.70e	37.64e	24.31f	8.75g	30.64f
	5	15.97g	43.58e	58.92d	97.84a	94.86a	83.69b	67.02c	32.02f	20.70g	57.18d
Commercial eucalyptus oil	1	26.91f	32.00f	35.05e	35.39e	34.54e	26.74f	24.65f	19.10g	16.53g	27.88f
	2.5	37.73e	45.78e	53.57d	60.62d	69.98c	66.89c	53.45d	33.15f	15.96g	48.57d
	5	56.37d	71.84c	76.75b	87.74b	89.83a	83.71b	74.20b	34.99e	20.85g	66.25c
Commercial eucalyptus oil nanocapsules	1	21.91g	30.50f	33.44f	35.43e	35.43e	34.77f	28.21f	26.85f	24.74f	30.14f
	2.5	12.66g	46.47e	54.08d	74.72b	70.75c	69.05c	61.42c	29.81f	24.23f	49.24d
	5	53.89d	79.96b	90.79a	95.57a	90.76a	86.35b	82.61b	70.81c	22.07f	74.76b
LSD 5%		12.01									

Note: The symbols “a,” “b,” “c,” “d,” “e,” “f,” and “g” denote the levels of statistical significance, indicating meaningful differences between the groups.

TABLE 6 | Effect of eucalyptus oil nanocapsules on adults of the whitefly *B. tabaci* on the Sierra Nevada variety.

Treatments	Conc. (%)	KE (%)									Avg.
		Days after spray									
		1	2	3	4	5	6	7	14	21	
Actara	200 g/ha	37.21e	55.44d	69.61c	81.97b	92.57a	96.42a	100.00a	95.63a	88.61a	79.72b
Extracted eucalyptus oil	1	35.25e	34.07e	32.40e	26.89f	27.30f	26.07f	19.81f	17.67f	17.43f	26.32f
	2.5	45.76d	50.14d	47.62d	45.36d	45.35d	38.29e	27.82f	21.87f	18.58f	37.87e
	5	49.03d	55.59d	56.87d	53.91d	54.01d	43.71d	41.70e	37.48f	31.37f	47.07d
Extracted eucalyptus oil nanocapsule	1	36.16e	36.30e	30.85e	28.76e	26.09f	24.75f	16.52f	16.88f	12.27g	25.40f
	2.5	53.64d	45.89d	43.05d	41.23e	43.53d	37.67e	31.84e	31.30e	15.17f	38.15e
	5	91.79a	85.16b	78.96b	69.00c	60.84c	34.21e	30.81e	25.49f	19.85f	55.12d
Commercial eucalyptus oil	1	47.90d	45.02d	41.55e	35.79e	39.89e	36.87e	33.34e	32.71e	32.16e	38.36e
	2.5	38.07e	36.35e	34.62e	34.24e	34.51e	31.01e	30.61e	23.73f	21.46f	31.62e
	5	79.53b	78.30b	75.61b	67.79c	64.24c	60.30c	48.73d	46.76d	27.18f	60.94c
Commercial eucalyptus oil nanocapsule	1	29.61e	31.72e	25.20f	24.57f	20.93f	19.86f	16.11f	15.41f	11.59g	21.67f
	2.5	45.32d	46.05d	42.16e	42.55e	40.72e	38.14e	34.28e	26.06f	23.55f	37.65e
	5	87.42a	83.92b	82.15b	81.96b	78.64b	76.31b	73.16b	58.99c	48.35d	74.54b
LSD 5%		14.10									

Note: The symbols “a,” “b,” “c,” “d,” “e,” “f,” and “g” denote the levels of statistical significance, indicating meaningful differences between the groups.

the embryo inside the egg [29]. In addition to the role of plant extracts in combating insects at all growth stages, whether nymphs or adults. Bowers [30] indicated that some plant compounds may be involved in damaging the epithelial cells lining

the middle gastrointestinal tract of the insect that feeds on these compounds. Besides, these toxic compounds affect the nervous system of the insect, causing paralysis and then failure to continue its growth.

These results also indicate that the reduction percentage may persist for a longer period after treatment by eucalyptus oil forms. Although more days passed after treatment, the reduction percentage remained at high rates. The reason may be that the plant extract remains on parts of the crop or on the insect itself, so its effect persists in the rest of the individuals. This is consistent with what Asawalam [31] mentioned: that the longer the effect of the extract remains on the insect's body, the greater the reduction percentage might be attributed to the highest component, 1,8-cineole (70.94%), which can be used as a botanical pesticide agent for insect control [32], as well as to oxygen deprivation. Watson et al. [33] demonstrated that a high reduction percentage may be due to the absence of eggs or the decrease in their numbers after treatment in various treatments, and this may be attributed to the effect of different chemical treatments on adult insects and the death events in them, which is reflected in the number of eggs laid on the leaves of orange trees.

The study showed that the effect of some treatments has faded over time, which can be attributed to the decline of active substances or the fact that the concentration used may be quite low. Hence, there is no effect on the individuals of the pest to be controlled. The greater effectiveness of eucalyptus extract was achieved at the higher concentration. Similarly, Wahba et al. [34] who reported that the effect of eucalyptus oil decreased over time, suggesting that the active compound in the extract faded.

As for the pesticide Actara, it was the most effective across the various stages of the whitefly, achieving a 100% reduction. Despite the existence of many modern control methods, it proved the efficiency of using insecticides to control pests, as studies were conducted urging the modern use of modern pesticide technologies instead of the use of large doses [35]. Similarly, Al-Dahwi et al. [36] reported high efficiency of Actara pesticide against whiteflies on potato crops, as the effectiveness of the pesticide continued for 5 weeks after treatment.

4 | Conclusions

Eucalyptus oil normal and nanoformulations have an efficient insecticidal activity against *B. tabaci* at all stages (eggs, nymphs, and adults). The 5% concentration was the best among the other treatments (except for the pesticide Actara) in inhibiting the whitefly at all stages. The nanocapsules of extracted eucalyptus oil were the best among other treatments in controlling whiteflies on both varieties (Charisma and Sierra Nevada) of sweet pepper.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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