Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Determination of fumigant toxicity of single, binary and tertiary mixtures of three essential oils against Frankliniella occidentalis Pergande (Thysanoptera: Thripidae)

Musa KIRIŞIK (musa_0007@hotmail.com)
Batı Akdeniz Agricultural Research Institute

Research Article

Keywords: Frankliniella occidentalis, western flower thrips, Essential oil, Fumigant toxicity

Posted Date: November 29th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2302494/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Abstract

In this study, three essential oils extracted from sage (*Salvia officinalis* L.), thyme (*Thymus vulgaris* L.) and daphne (*Laurus nobilis* L.) were used against the adult *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) pest, one by one and more Then, fumigant toxicity of binary (1:1) and tertiary (1:1:1) mixtures was investigated under laboratory conditions. The results showed that all essential oils tested, both alone and in all binary and tertiary mixtures, had fumigant toxicity on adult *F. occidentalis*. Mortality rates of 3–5 day old adults of *F. occidentalis* increased with increasing concentration from 20 to 100 µL/L. In the entire study, binary and tertiary mixtures of the oils were more successful than the individual application. At a dose of 10 µL/L, all binary and tertiary mixtures of the oils caused 100% mortality at all exposure time periods. However, in the application where sage oil was fumigated for 24 hours and applied alone, the mortality rate remained below 100%. The highest synergistic effect was found in triple essential oil mixtures (sage + daphne + thyme) with 1.0 µL/L air LC_{50} value in all application doses, counted after 48 hours. Our overall results show that binary and tertiary mixture of all tested essential oils are promising candidates for protection against western flower thrips.

Background

Insects, which are one of the most important factors limiting agricultural production, cause significant product losses if not management. Among them, the important quarantine pest *Frankliniella occidentalis* (Thysanoptera: Thripidae) is a species that causes serious damage in the world and in Turkey. This polyphagous species has a wide range of hosts such as greenhouse, cotton and ornamental plants. In our country, complaints about the pests in greenhouses, especially in pepper greenhouses, are increasing day by day.

The high doses and frequent sprayings applied by the farmers have led to an increase in the resistance that has developed since the 1980s, and the resistance of many insecticides against *F. occidentalis* has been determined until today (Cloyd, 2016; Dağlı, 2018). Due to the fact that the pest in question gives a large number of offspring during the year, resistance to insecticides can occur in a short time. This situation leads to intensive chemical applications and harms the environment and natural enemy population. For this reason, it has become a necessity to develop environmentalist, protective and alternative methods of management.

In recent years, plant extracts and essential oils have started to be seen as an alternative to chemical pesticides in the managament against agricultural pests. The use of herbal extracts as insecticides dates back to ancient times. Helleborus plant (Christmas rose flower) was used as a natural insecticide in Roman times (Smith & Secoy, 1975). These substances, which are being researched with increasing interest today, have different effects against pests such as insecticidal, repellent, anti-feedant and growth inhibitory, and egg laying inhibitor have been identified (Jannet et al., 2001; Sampson et al., 2005; Kumral et al., 2010; Taş, 2011). In addition, it is reported that the contact effect of herbal extracts against many pests is successful (Karakoç & Gökçe, 2012; Taş et al., 2015).

Similarly, the use of plant-derived essential oils as insecticides has been one of the important research topics. High lipophilic (water-insoluble) essential oil components can dissolve in fatty tissues when taken into the harmful body due to these properties, making the fight even easier (Tsao et al., 1995). It has been determined that vegetable oils have different effects against pests such as toxic, repellent, nutritional inhibitor, growth and reproduction inhibitor (Shaaya et al., 1993; Ndungu et al., 1995; Isman, 2000). The majority of research on the use of essential oils as insecticides has focused on the fumigant effect of these alternative control agents (Prates et al., 1988; Tsao et al., 1995). However, research on the contact effect of essential oils has been limited. There is a need for alternative control agents with contact effect, which are more applicable in practical control, and it is predicted that essential oils will give positive results in this respect. As a matter of fact, there are studies reporting that essential oils have contact effects against pests (Palacios et al., 2009; Kumar et al. 2012; Zarrad et al., 2017; Campolo et al., 2017).

Although essential oils and extracts are known to contain volatile organic compounds with insecticidal, antibacterial, antifungal, anti-inflammatory, antioxidant, anticarcinogenic and antiviral activities, the direct use of oils is very limited due to their hydrophobicity and low stability. These compounds; They are adversely affected by environmental factors such as temperature, oxygen and humidity. The development of micro-nano emulsion and encapsulation formulations is a very effective and innovative solution to increase the water solubility of essential oils and to protect them against external factors. In addition, the development of these formulations allows some molecules to adhere better to the surface, increasing their effectiveness (Jamil, Bushra, et al., 2016).

In the last three decades, significant research has been conducted on the development of new botanical insecticides as an alternative to existing chemical insecticides (Erler, 2004; Çetin et al., 2004; Erler et al., 2007). Many essential oils and their components have been reported to have fumigant activity on thrips (Sedy & Koschier 2003; Stepanycheva et al., 2019; Gharbi and Tay, 2022). This study was carried out to determine the fumigant toxicity of some aromatic plant essential oils and mixtures against *F. occidentalis*, which is the main pest of many ornamental plants and vegetables.

Materials And Methods

Plant materials and essential oil extraction

Dry parts of sage (*Salvia officinalis* L.), thyme (*Thymus vulgaris* L.) and laurel (*Laurus nobilis* L.) were used for extraction. The collected plant materials were first naturally dried on laboratory benches for 5–7 days until crisp at room temperature (23–24°C) and then hydro-distilled to extract their essential oils. Taxonomic identification was made by subject experts in the Department of Food Technology and Medicinal and Aromatic Plants, Batı Akdeniz Agricultural Research Institute (BATEM), where the samples were stored.

Insect Material

Bean fruits were used to provide feeding and egg-laying environment for thrips. Plastic containers, the lids of which were covered with filter paper, were used as production cages and 2–3 layers of towel paper were laid on the bottom of them to pass the pupa stage of the thrips. Bean fruits, which were disinfected with bleach, dipped in sugar and amino acid solutions and dried, were left in the production cages together with the thrips desired to be produced, and the green bean fruits were replaced with new ones at 3–4 day intervals. The thrips were reared in a climate chamber with a temperature of 24 ± 1ºC and a day length of 16:8 h (light: dark). Adult insects aged 3–5 days were used for fumigant toxicity tests. All trials were carried out under the same conditions.

Fumigant Toxicity Tests

Effectiveness of the tested essential oils as fumigant against adults of *F. occidentalis* were carried out in the laboratory of the Department of Plant Health, Batı Akdeniz Agricultural Research Institute (BATEM). Fumigant toxicity tests were carried out according to the method described by Erler (Erler 2005; Erler 2007).

To determine the fumigant toxicity of essential oils and their binary and tertiary mixtures, desiccators with a net volume of 10 L were used. Four replicates were used for each dose and combination. Each dose was applied with an automatic pipette on a blotter (9 cm in diameter) adhered to the underside of the desiccator cover. Then, the vaseline-applied desiccator lids were tightly closed in an air-tight manner. Preliminary tests were conducted to determine the appropriate dose and dose ranges. Application doses are determined as 2, 4, 8 and 10 µL/L air. The binary dose mixtures of the tested essential oils were prepared in the ratio of 1:1 and the tertiary mixtures were prepared in the ratio of 1:1:1. The experiment was started by placing the desiccators under controlled conditions (26 ± 1 C° temperature, 60 ± 5% proportional humidity). In agricultural applications, the maximum closed period of greenhouses takes about 8 hours. For this reason, in this study, the fumigation time was chosen as 8 hours, taking into account the aquaculture practices. At the end of this period (8 h), the desiccators were opened and the fumigation effect was removed and the petri dishes were kept in an open environment for 48 hours. During this period, dead and live individuals were counted at 8, 24 and 48 hours and the continuing effect of the application was revealed. Insects were considered dead when no leg or antennae movement was observed when poked with a fine brush.

Determination Of Phytotoxic Effects Of Essential Oils (Dup: Abstract ?)

In order to determine the phytotoxic effects of essential oils on vegetables, tomato, eggplant, cucumber and bean types, which are mostly grown in Antalya region, were selected. For this, Erciyes cultivars for pepper, Phaselis F1 for eggplant, PTK 40 for cucumber and Özayşe for beans were used. The plants were grown in climate rooms with 26 ± 1C° temperature, 65 ± 5% RH and 18:6 lighting period. Each seedling was transplanted into 12 x 10 cm pots containing a sterile mixture of 2 parts peat + 1 part perlite. When

the plants reach approximately 15 cm (3–4 leaves) in length, they were placed in desiccators as in other fumigant effect trials, the highest doses for each essential oil (*S. officinalis*: 10 µl/l; *T. vulgaris*: 10 µl/l; *L. nobilis*: 10 µl/l; each dose was prepared as 1:1 in binary and 1:1:1 in the tertiary mixtures of the tested essential oils) was sucked onto the blotting paper (9 cm in diameter) adhered to the inside of the desiccator cover with the help of a micropipette, and the desiccator cover was closed without delay and fumigation was done for 8 hours. At the end of the fumigation, the plants removed from the desiccators were observed for 48 hours, and the signs of phytotoxicity were recorded. Experiments were carried out with 5 replications for each plant, in control and essential oil.

Data analysis

The mortality rates obtained from the trials were analyzed using the SPSS program after the corrected mortality rates were calculated with the Abbott formula, and statistical differences between the means were tried to be revealed with the DMRT ($P \leq 0.05$). While determining the fumigant effect, the data obtained from the adult effects trials were calculated according to the probit analysis method (POLO-PC, LeOra Software, 1997, Berkeley, CA, USA) as LC_{50}, LC_{90} values at a 95% confidence interval.

Results

One of the important effects of essential oils on pests is fumigant effect. The chemical compositions of the essential oils used within the scope of this research are given in Table 1.

Table 1
Chemical composition of investigated essential oil samples

Daphne	% Total	Thyme	% Total	Sage	% Total
Alpha-pinene	6.46	Cymene	0.82	Tricyclene	0.45
Beta-pinene	4.74	Linalool	1.60	Alpha-Pinene	25.85
Sabinene	9.23	Terpinen-4-ol	0.51	Alpha-Thujene	0.50
Beta-myrecene	0.65	Alpha-terpineol	0.50	Camphene	10.07
Alpha-terminene	0.50	Borneol	0.72	Beta-Pinene	8.71
Limonene	1.59	Beta-bisabolone	0.42	Sabinene	0.42
1,8-cineole	57.49	Thymol	1.48	Beta-Myrcene	1.85
Gamma-terpinene	1.21	Carvacrol	93.95	Limonene	2.51
Cymene	1.63			1,8-Cineole	17.81
Linalool	0.99			Cymene	1.41
Terpinen-4-ol	3.09			Camphor	13.87
Alpha-terpineol	1.5			Linalool	1.08
Alpha-terpinyl acetate	9.65			Bornyl Acetate	2.05
Methyl eugenol	0.64			Terpinen-4-Ol	0.70
Undefined	0.65			Beta-Caryophyllene	3.42
				Alpha-Humulene	1.49
				Alpha-Terpineol	0.77
				Borneol	5.06
				Delta-Cadinene	0.37
				Caryophyllene Oxide	0.67
				Undefined	0.96

In addition, in this study, the fumigant effects of different concentrations of essential oils of *F. occidentalis* on adults were investigated (Table 2). Fumigation was applied to the adult period of the pest for 8 hours. Adults were counted as dead and alive in different periods up to the 48th hour, LC_{50} and LC_{90} values of essential oils were calculated from the data obtained (Table 2–3) (Table 4).

Table 2

Mean percent mortality of 3-5-day-old adults of *Frankliniella occidentalis* exposed to the vapours of three essential oils for various dose x exposure time combinations.

Essential oils	Time (h)	Mortality (Mean ± S.E.)			
		Treatment concentrations (µL/L air)			
		2	**4**	**8**	**10**
Thyme	8	47.4 ± 1.6 Db	54.7 ± 2.6 Cc	78.5 ± 1.9 Bb	98.5 ± 0.5 Aa
	24	53.3 ± 1.4 Da	59.7 ± 2.0 Cb	83.3 ± 1.8 Ba	100.0 ± 0.0 Aa
	48	56.8 ± 1.4 Da	63.3 ± 1.1 Ca	86.5 ± 2.5 Ba	100.0 ± 0.0 Aa
Sage	8	10.5 ± 0.9 Cb	25.6 ± 3.4 Bc	39.0 ± 4.7 Ab	49.5 ± 4.0 Ac
	24	16.5 ± 5.3 Ca	31.7 ± 5.3 Bb	47.9 ± 5.1 Aa	54.7 ± 3.4 Ab
	48	18.6 ± 5.8 Ca	35.7 ± 4.3 Ba	51.0 ± 4.9 Aa	60.6 ± 2.2 Aa
Daphne	8	36.6 ± 1.6 Dc	53.9 ± 1.3 Cb	82.9 ± 0.3 Bc	97.7 ± 0.5 Aa
	24	42.4 ± 1.0 Db	62.6 ± 2.0 Ca	87.6 ± 1.0 Bb	100.0 ± 0.0 Aa
	48	48.7 ± 1.7 Da	67.6 ± 2.0 Ca	91.7 ± 0.5 Ba	100.0 ± 0.0 Aa

* In each treatment, means within a row followed by the same capital letter are not significantly different (DMRT, $P \leq 0.05$).

** In each treatment, means within a column followed by the same lower case letter are not significantly different (DMRT, $P \leq 0.05$).

Table 3

Mean percent mortality of 3-5-day-old adults of *Frankliniella occidentalis* exposed to the vapours of binary and tertiary mixtures of three essential oils for various dose x exposure time combinations

Essential oils	Time (h)	Mortality (Mean ± S.E.)			
		Treatment concentrations (µL/L air)			
		2	**4**	**8**	**10**
Thyme + Sage	8	46.4 ± 2.3 Db	59.8 ± 2.9 Cc	81.9 ± 0.2 Bc	93.0 ± 0.4 Aa
	24	51.4 ± 2.4 Db	66.1 ± 2.7 Cb	86.9 ± 0.3 Bb	96.8 ± 0.5 Aa
	48	59.1 ± 1.8 Da	72.5 ± 1.6 Ca	92.5 ± 0.6 Ba	99.9 ± 0.1 Aa
Daphne + Sage	8	25.2 ± 5.1 Cs	39.2 ± 3.0 Bc	49.1 ± 4.7 ABc	60.1 ± 3.5 Ac
	24	29.1 ± 6.7 Cb	45.4 ± 2.4 Bb	54.2 ± 4.3 ABb	65.5 ± 3.3 Ab
	48	34.0 ± 5.4 Ca	52.8 ± 2.3 Ba	60.0 ± 3.8 Ba	72.8 ± 2.5 Ab
Thyme + Daphne	8	57.1 ± 2.7 Dc	66.2 ± 2.8 Cc	83.4 ± 1.0 Bc	98.9 ± 0.2 Aa
	24	62.5 ± 2.7 Db	71.8 ± 2.6 Cb	88.3 ± 1.0 Bb	100.0 ± 0.0 Aa
	48	71.2 ± 3.6 Da	78.7 ± 1.4 Ca	93.6 ± 0.5 Ba	100.0 ± 0.0 Aa
Thyme + Sage + Daphne	8	67.2 ± 1.3 Dc	72.7 ± 1.6 Cc	92.5 ± 0.4 Ba	99.2 ± 0.2 Aa
	24	71.9 ± 1.2 Db	78.8 ± 1.4 Cb	95.9 ± 0.8 Ba	100.0 ± 0.0 Aa
	48	78.4 ± 2.7 Da	83.0 ± 0.9 Ca	97.1 ± 1.5 Ba	100.0 ± 0.0 Aa

* In each treatment, means within a row followed by the same capital letter are not significantly different (DMRT, $P \leq 0.05$).

** In each treatment, means within a column followed by the same lower case letter are not significantly different (DMRT, $P \leq 0.05$).

Table 4
LC_{50} and LC_{90} values obtained as a result of 8 hours fumigation of essential oils to *Frankliniella occidentalis* adults

Essential oils	Time (h)	LC_{50} (µL/L air) (LCL-UCL)*	LC_{90} (µL/L air) (LCL-UCL)*	Slope (± SE)
Thyme	8	2.9 (2.0-3.7)	11.6 (8.4–21.2)	2.1 ± 0.1
	24	2.5 (1.6–3.2)	9.7 (7.2–16.7)	2.1 ± 0.1
	48	2.0 (1.1–2.7)	8.9 (6.5–16.6)	2.0 ± 0.1
Sage	8	13.9 (10.3–25.9)	69.8 (33.8-415.6)	1.8 ± 0.1
	24	12.2 (8.3–32.2)	106.2 (37.3-3202.2)	1.3 ± 0.1
	48	9.5 (7.0-16.4)	68.0 (30.5-537.7)	1.5 ± 0.1
Daphne	8	3.4 (2.8–3.9)	9.9 (8.2–12.9)	2.7 ± 0.1
	24	2.8 (2.3–3.3)	8.4 (6.9–11.0)	2.7 ± 0.1
	48	2.4 (2.0-2.8)	7.1 (6.1–8.8)	2.8 ± 0.1
Thyme + Sage	8	2.7 (2.2–3.4)	11.5 (9.2–15.7)	2.1 ± 0.1
	24	2.5 (2.0-2.9)	9.0 (7.5–11.6)	2.3 ± 0.1
	48	1.9 (1.4–2.3)	7.0 (5.9–8.8)	2.2 ± 0.1
Daphne + Sage	8	10.3 (7.2–22.5)	149.5 (47.8-4523.7)	1.1 ± 0.1
	24	7.3 (5.4–11.9)	99.0 (37.4-1429.6)	1.1 ± 0.1
	48	5.1 (3.8–6.7)	60.9 (28.8-342.5)	1.2 ± 0.1
Thyme + Daphne	8	2.1 (1.2–2.8)	10.0 (7.4–17.7)	1.9 ± 0.1
	24	1.7 (1.0-2.3)	7.7 (6.0-11.6)	2.0 ± 0.1
	48	1.3 (0.8–1.7)	5.6 (4.6–7.3)	2.0 ± 0.1
Thyme + Sage + Daphne	8	1.5 (0.9-2.0)	6.8 (5.5–9.5)	1.9 ± 0.1
	24	1.3 (0.7–1.7)	5.2 (4.3–6.9)	2.1 ± 0.1
	48	1.0 (0.5–1.4)	4.4 (3.6–5.6)	2.0 ± 0.1
*: % 95 confidence limit (LCL: lower concentration limit; UCL: upper concentration limit)				
SE: Standart error				

All essential oils tested, both alone and in binary and tertiary mixtures, showed differential fumigant toxicity for adults of *F. occidentalis* at all dose x exposure time combinations tested (Tables 2 and 3).

Overall, mortality was seen to increase with increasing dose from 2 to 10 µL/L air and with increasing count time from 24 hours to 96 hours.

Among the essential oils tested, thyme and laurel oil were the most successful, yielding 100% mortality at the highest dose (10 µL/L air) at the 24th and 48th hour counts (Table 2). In contrast, laurel oil at the highest dose (10 µL/L air) had lower mortality rates than laurel and thyme. Thyme and laurel showed a similar high effect (Table 2).

Compared to the single applied essential oils, the mortality rates of the binary and tertiary mixtures of essential oils were higher. In the 24th and 48th hour counts of thyme + daphne oil mixtures, 100% mortality was achieved at the highest dose (10 µL/L air) (Table 3). In the 48 hour count, high mortality rate (99.9%) was determined in the thyme + sage mixture, but 72.8% mortality rate was determined in the highest dose (10 µL/L air) in the daphne + sage mixture. In addition, the triple mixture of these oils (thyme + sage + daphne) achieved more successful results than all binary mixtures (Table 3).

LC_{50} and LC_{90} values calculated from live/dead individual counts made at different times after fumigation of *F. occidentalis* adults with essential oils at different concentrations are given in Table 4. When Table 4 is examined, the LC_{50} value calculated with the data obtained from the 8th hour counts was found to be 2.9 µl/l for thyme essential oil, 13.9 µl/l for sage and 3.4 µl/l for daphne. The LC_{50} values calculated with the data obtained from the 8th hour counts in the mixtures oils are determined as 2.7 µl/l for the thyme + sage mixture, 10.3 µl/l for the daphne + sage mixture, 2.1 µl/l for the thyme + laurel mixture and 1.5 µl/l for the thyme + sage + daphne triple mixture. These values decreased gradually for the following counting periods and decreased to 2.0 µl/l for thyme essential oil, 12.2 µl/l for sage and 2.4 µl/l for daphne at the end of the 48th hour, respectively. For mixed oils, these values decreased gradually for the following counting periods and were determined as 1.9 µl/l for thyme + sage mixture, 5.1 µl/l for laurel + sage mixture, 1.3 µl/l for thyme + daphne mixture and 1.0 µl/l for thyme + sage + daphne tertiary mixture. LC_{90} values are similar to LC_{50} values, and a decrease in LC values has been detected in all oils and oil mixtures in general at increasing counting hours. This situation was reflected in the results of the probit analysis.

Determination Of Phytotoxic Effects Of Essential Oils

Observations were made in terms of phytotoxicity in plants until the 48th hour after the eight-hour fumigation process, and no phytotoxic effects were found on tomato, eggplant cucumber and bean plants with single, binary and tertiary mixtures of three essential oils. In general, no adverse events were observed in all control group plants, which were kept in the same conditions as the treated plants but were not subjected to essential oil fumigation.

Discussion

The use of plant essential oils is an alternative to chemical insecticides for the control of thrips and poses a low risk to human health (Sedy and Koschier 2003; Stepanycheva et al., 2019 Gharbi & Tay, 2022). Binary mixtures of essential oils from different plant species can increase their toxic effects against pests (Benelli et al., 2017). In this study, it was determined that the mixture of essential oils of laurel, thyme and sage is toxic for the adult female period of *F. occidentalis*.

The effectiveness of many essential oils as a fumigant to control *F. occidentalis* has been investigated and it has been observed that this insect is sensitive to some plant-derived chemicals. However, although there are existing publications on the fumigant activity of the essential oils tested in the current study against *F. occidentalis*, the effect of these oils individually and in their mixtures against the pest was determined for the first time.

Koschier et al., 2000, in their study, investigated the responses of adult female *F. occidentalis* to plant volatiles at various concentrations in Y tube olfactometry. At the end of the research, Western flower thrips were attracted by the benzenoids benzaldehyde and p- and o-anisaldehyde. p-Anisaldehyde, nerol, ethyl nicotinate and (E)-b-farnesene elicited positive responses at various concentrations.

Sedy & Koschier, 2003, two components of essential oils, carvacrol and thymol, were tested for their effects on the feeding activity, egg-laying preference and oviposition rate of *F. occidentalis*. In our study, the fumigation effect of oils was examined, while the researchers examined the contact effect by spraying a commercial preparation containing carvacrol and thymol with a spray-tower. As a result of the study, both components acted as anti-ovipositants for *F. occidentalis*. In our study, thyme oil was found to have a high lethal effect for *F. occidentalis*, both single and in mixtures, with its high carvacrol (93.95) content.

Stepanycheva et al., 2019, investigated the acute toxicity results of 15 commercial essential oils administered by fumigation and the effect of sublethal concentrations on the fertility of *F. occidentalis* females. The LC_{50} value of *Thymus mastichina* species thyme was determined as 3.6 mg/L and the LC_{90} value as 4.6 mg/L. In our study, the LC50 value was determined as 2.0 µL/L and the LC90 value as 8.9 µL/L after 48 hours in the application of thyme.

Allsopp et al., 2019, the effectiveness of different carvacrol concentrations on *F. occidentalis* individuals was investigated by experiments on plum blossoms. Carvacrol concentrations of 5%, 1%, and 0.1% were found to significantly reduce spawning rate (84%, 53%, and 57%, respectively) compared to untreated flowers. In our study, 4 different concentrations were used and at the end of 48 hours, 56.8, 63.3, 86.5 and 100.0 mortality values were obtained at 2, 4, 8 and 10 µL/L doses, respectively.

Picard et al., 2019, investigated the repellent activity of 8 different essential oils on *F. occidentalis* females in their study. The results showed that at a concentration of 0.5% *Thymus vulgaris* L. (thyme) and *Satureja montana* L. (winter scent) were the most repellent essential oils. If we need to correlate this study with our study, it can be said that both the repellent and fumigant effects of thyme oil are high against *F. occidentalis* individuals.

Stepanycheva et al., 2018, presented the results of the evaluation of the effects of essential oils on *F. occidentalis* behavior and reproductive potential in their study. As a result of their studies, it was determined that essential oils of *Acorus calamus, Juniperus virginiana* and *Melissa officinalis* have a repellent effect on *F. occidentalis* larvae.

Gharbi & Tay 2022, investigated the effectiveness of different linalool polymers on adults of *F. occidentalis* in their study. In the study, (R)-linalool was found to be more toxic than (S)-linalool, with LC_{50} values of 29.0 mg/L air and 34.9 mg/L air, respectively. In our study, linalool content was determined in laurel, thyme and sage, but since this rate is around 1% of the total content in all three plants, it is thought that its contribution to the mortality rate is not high.

Janmaat et al., 2002, in their study, investigated the effectiveness of the *p*-cymene essential oil component on *F. occidentalis* adult females, 1st and 2nd instar larvae and eggs using the fumigation method. When *p*-cymene was fumigated with carbon dioxide, it was observed that the pest reached a high mortality rate on adults and 1st and 2nd instar larvae. In our study, cymene content was determined in daphne, thyme and sage, but since this rate is around 1% of the total content in all three plants, it is thought that its contribution to the mortality rate is not high.

Conclusion

According to the findings, binary and tertiary essential oil combinations are more active than individual oils (Tables 2 and 3). This suggests a possible synergism, and the usage of combinations of plant essential oils may be more effective than individual oils in protecting stored items.

Essential oils, as opposed to conventional fumigants, offer some benefits since they have been employed in traditional medicine, medicinal preparations, herbal beverages, and as natural flavorings. As a result, they are thought to be neither more or less detrimental to human health than traditional fumigants. Furthermore, it has been observed that essential oils with fumigant activity have little mammalian toxicity.

Finally, the study shows good outcomes for reducing *F. occidentalis* population on vegatable glasshouses.

Abbreviations

LC: Lethal concentration; BATEM: Bati-Akdeniz Agricultural Research Institute; RH: Relative humidity; L:D: Light: Dark; DMRT: Duncan's Multiple Range Test

Declarations

Acknowledgements

The author gratefully thanked the Department of Food Technology and Medicinal and Aromatic Plants, Batı Akdeniz Agricultural Research Institute (BATEM) for providing the identification and supply of the essential oils used in the study.

Authors' contributions

The author read and approved the final manuscript.

Competing interests

The author declare that he has no competing interests.

Funding

Not applicable.

Availability of data and materials

All data generated or analyzed in this study are available in this published manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable

References

1. Allsopp, E., Prinsloo, G. J., Smart, L. E., & Dewhirst, S. Y. (2014). Methyl salicylate, thymol and carvacrol as oviposition deterrents for *Frankliniella occidentalis* (Pergande) on plum blossoms. *Arthropod-Plant Interactions*, *8*(5), 421-427.
2. Benelli, G., Pavela, R., Canale, A., Cianfaglione, K., Ciaschetti, G., Conti, F., Nicoletti, M., Senthil-Nathan, S., Mehlhorn, H., & Maggi, F. (2017). Acute larvicidal toxicity of five essential oils (*Pinus nigra, Hyssopus officinalis, Satureja montana, Aloysia citrodora* and *Pelargonium graveolens*) against the filariasis vector *Culex quinquefasciatus*: Synergistic and antagonistic effects. Parasitology International, 66(2), 166–171. https://doi.org/10.1016/j.parint.2017.01.012
3. Campolo, O., Cherif, A., Ricupero, M., Siscaro, Gaetano, K., Lebdi,G., Russo, A., Cucci, L. M., Pietro, P.D, Satriano, C., Desneux, N., Biondi, A., Zappalà, L., & Palmeri, V. (2017). Citrus peel essential oil nanoformulations to control the tomato borer, *Tuta absoluta*: chemical properties and biological activity. *Scientific Reports* 7: *13036* | DOI:10.1038/s41598-017-13413-0. www.nature.com/scientificreports/

4. Cloyd, R.A. (2016). Western flower Thrips (Thysanoptera: Thripidae) and insecticide resistance: an overview and strategies to mitigate insecticide resistance development. *J. Entomol. Sci.,* 51(4):257–73.
5. Çetin, H., Erler, F., & Yanikoglu, A. (2004) Larvicidal activity of a botanical natural product (AkseBio2) against *Culex pipiens* L. Fitoterapia 75, 724-728.
6. Dağlı, F. (2018). Spinosad resistance in a population of *Frankliniella occidentalis* (Pergande, 1895) from Antalya and its cross resistance to acrinathrin and formetanate. *Türk. entomol. derg.,* 42 (4): 241-251.
7. Erler, F. (2004) Laboratory evaluation of a botanical natural product (AkseBio2) against the pear psylla *Cacopsylla pyri*. Phytoparasitica 32, 351-356.
8. Erler, F. (2005) Fumigant activity of six monoterpenoids from aromatic plants in Turkey against the two storedproduct insects confused flour beetle, *Tribolium confusum*, and Mediterranean flour moth, *Ephestia kuehniella*. Z. Pflanzenk. Pflanzen. 112, 602-611.
9. Erler, F. (2007) Fumigant activity of monoterpenoids against the rice weevil, *Sitophilus oryzae* (L.). IOBC/wprs Bulletin 30(2), 281-285.
10. Erler, F., Yegen, O., & Zeller, W. (2007) Field evaluation of a botanical natural product against the pear psylla (Homoptera: Psyllidae). J. Econ. Entomol. 100, 66-71
11. Gharbi, K., & Tay, J. W. (2022). Fumigant Toxicity of Essential Oils against *Frankliniella occidentalis* and *F. insularis* (Thysanoptera: Thripidae) as Affected by Polymer Release and Adjuvants. Insects, 13(6), 493.
12. Isman, M.B., (2000). Plant essential oils for pest and disease management, *Crop Protection*, 19: 603-608.
13. Jamil, B., Abbasi, R., Abbasi, S., Imran, M., Khan, S. U., Ihsan, A., & Bokhari, H. (2016). Encapsulation of cardamom essential oil in chitosan nano-composites: in-vitro efficacy on antibiotic-resistant bacterial pathogens and cytotoxicity studies. *Frontiers in microbiology*, *7*, 1580.
14. Janmaat, A. F., Kogel, W. J. D., & Woltering, E. J. (2002). Enhanced fumigant toxicity of p-cymene against Frankliniella occidentalis by simultaneous application of elevated levels of carbon dioxide. *Pest Management Science: formerly Pesticide Science*, *58*(2), 167-173.
15. Jannet, H.B., H-skhiri, F., Mighri, Z., Simmonds, M.S.J., & Blaney, W.M. (2001). Antifeedant activity of plant extracts and of new natural diglyceride compounds isolated from *Ajuga pseudoiva* leaves against *Spodoptera littoralis*. Industrial crop and product, 14, 213-222.
16. Karakoç, Ö. C., & Gökçe, A. (2012). Bitki ekstraktlarının Spodoptera littoralis (Lepidoptera: Noctuidae)'e olan kontak toksisiteleri. *Türkiye Entomoloji Dergisi*, *36*(3), 423-431.
17. Koschier, E. H., De Kogel, W. J., & Visser, J. H. (2000). Assessing the attractiveness of volatile plant compounds to western flower thrips *Frankliniella occidentalis*. *Journal of Chemical Ecology*, *26*(12), 2643-2655.
18. Kumar, P., Mishra, S., Malik, A., & Satya, S. (2012). Insecticidal evaluation of essential oils of *Citrus sinensis* L. (Myrtales: Myrtaceae) against housefly, *Musca domestica* L. (Diptera: Muscidae).

Parasitology Research, 110: 1929-1936

19. Kumral, N. A., Çobanoğlu, S., & Yalçın, C. (2010). Acaricidal, repellent and oviposition deterrent activities of *Datura stramonium* L. against adult *Tetranychus urticae* (Koch). Journal of Pest Science, 83, 173–180.
20. Ndungu, M., Lwande, W., Hassanali, A., Moreka, L., & Chhabra, S.C., (1995), *Cleome monophylla* essential oil and its constituents as tick (*Rhipicephalus appendiculatus*) and maize weevil (*Sitophilus zeamais*) repellents, *Entomology Experimentalis et Applicata.,* 76: 271-222.
21. Palacios, S.M., Bertoni, A., Rossi, Y., Santander, R., & Urzúa, A. (2009). Efficacy of essential oils from edible plants as insecticides against the house fly, *Musca domestica* L. *Molecules,* 14: 1938-1947.
22. Picard, I., Hollingsworth, R. G., Salmieri, S., & Lacroix, M. (2012). Repellency of essential oils to *Frankliniella occidentalis* (Thysanoptera: Thripidae) as affected by type of oil and polymer release. *Journal of economic entomology*, *105*(4), 1238-1247.
23. Prates, H.T., Santos, J.P., Waquil, J.M., Fabris, J.D., Oliveira, A.B., & Foster, J.E., (1988). Insecticidal activity of monoterpenes against *Rhysopertha dominica* (F.) and *Tribolium castaneum* (Herbst.), *Journal of Stored Products Research*, 34 :243-249.
24. Sampson, B.J., Tabanca, N., Kirimer, N., Demirci, B., Baser, H.C., Khan, I.A., Spiers, J.M., & Wedge, D.E. (2005). Insecticidal Activity of 23 Essential Oils and their Major Compounds against Adult *Lipaphis pseudobrassicae* (Davis) (Aphididae: Homoptera). *Pest. Manag. Sci*., 61:1122–1128.
25. Sedy, K. A., & Koschier, E. H. (2003). Bioactivity of carvacrol and thymol against *Frankliniella occidentalis* and Thrips tabaci. *Journal of Applied Entomology*, *127*(6), 313-316.
26. Shaaya,E., Ravid, U., Paster, N., Kostjukovsky, M., Menasherov, M. , & lotkin, S., (1993). Essential Oils and their Components as Active Fumigants against Several Species of Stored Product Insects and Fungi. *Acta Horticulturae, International Symposium on Medicinal and Aromatic Plants*, 344:131-137.
27. Smith, A. E., & Secoy, D. M. (1975). Forerunners of pesticides in classical Greece and Rome. *Journal of Agricultural and Food Chemistry*, *23*(6), 1050-1055.
28. Stepanycheva, E. A., Petrova, M. O., Chermenskaya, T. D., & Pavela, R. (2018). Effects of volatiles of essential oils on behavior of the western flower thrips *Frankliniella occidentalis* Perg.(Thysanoptera, Thripidae). *Entomological Review*, *98*(7), 801-806.
29. Stepanycheva, E., Petrova, M., Chermenskaya, T., & Pavela, R. (2019). Fumigant effect of essential oils on mortality and fertility of thrips *Frankliniella occidentalis* Perg. Environmental Science and Pollution Research, 26(30), 30885-30892.
30. Taş, M. N. 2011. Bazı Bitki Ekstraktlarının *Callosobruchus maculatus* (F.) (Col.: Bruchıdae)'a Etkileri Üzerinde Araştırmalar. Selçuk University, Master Thesis, Konya.
31. Taş, M. N., Uysal, M., & Çetin, H.(2015). Bazı bitki ekstraktlarının Callosobruchus maculatus (F.)(Col.: Bruchidae)'e olan kontak toksisiteleri. *Bitki Koruma Bülteni*, *55*(3).
32. Tsao, R., Lee, S., Rice, P. J., Jensen, C., & Coats, J. R. (1995). Monoterpenoids and Their Synthetic Derivatives as Leads for New Insect-Control Agents. *Entomology Publications*. 369.

33. Zarrad, K., Chaieb, I., Hamouda, B. A., Bouslama, T. & Laarif, A. (2017). Chemical composition and insecticidal effects of *Citrus aurantium* essential oil and its powdery formulation against *Tuta absoluta*. *Tunisian Journal of Plant Protection,* 12: 83-94.