RESEARCH ARTICLE

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Inhibitory effect of plant essential oils on controlling *Alternaria* species

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Abstract

The use of natural products in the control of fungal diseases in plants is considered an alternative to synthetic fungicides due to their less negative effects on the environment. In this study, *in vitro* inhibitory effect of plant essential oils (PEOs) of black cumin, cumin, chamomile, cedarwood, and ginger were investigated for controlling two species of Alternaria, including *Alternari solani* and *Alternaria alternata* on tomato and cabbage under *in vitro* conditions, respectively. Aiming to evaluate the mycelial growth of the pathogen, mycelial discs were placed in Petri plates with 0, 500, 1000, 1500, 2000, and 2500 µL/L of PEOs. The experiment was carried out in a randomized plot design with three replications. Chemical analysis of PEO components were determined by Gas Chromatography and Mass Spectrometry methods. A total of 69 chemical compounds were determined in five different PEOs. As the main chemical compounds, Cuminaldehyde was detected in cumin PEO, Sesquithujene was found in ginger PEO, and Eucalyptol (1,8-cineole) was determined in black cumin, chamomile, and cedarwood PEOs. All five PEOs were found to inhibit the growth of *Alternaria* species in a dose-dependent manner, whereas cumin EO was determined more inhibitory effect against *A. solani* and *A. alternata*. Cumin PEO showed the highest effect against *Alternaria* species because it contains a Cuminaldehyde chemical compound. The lowest inhibition percentage was found in chamomile PEO compared to other PEOs. This study suggested that cumin PEO has the potential as an antifungal agent for controlling of Alternaria diseases.

Keywords: Essential oil, *Alternaria solani*, *Alternaria alternata*, Cuminaldehyde, Eucalyptol, Inhibition

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INTRODUCTION

The genus *Alternaria* was first introduced by Nees (1816), kingdom Mycota, phylum Ascomycota, class Dothideomycetes, order Pleosporales belongs to the family Pleosporaceae and is a ubiquitous genus of fungi that includes saprophytic, endophytic and pathogenic species (Saharan et al., 2016). The *Alternaria* genus has a wide variety of species around the world. Approximately 400 plant species are hosts of *Alternaria* species, including various species of crops, fruits, vegetables, ornamentals, and weeds (Leyva Salas et al., 2017; Meena et al., 2017; Gou et al., 2022). Among these species, *Alternaria solani* and *Alternaria alternata* cause early blight disease in many plants.

A. alternata is an endophytic species and is among the important seed-borne plant pathogens. *A. alternata* can produce more than 30 mycotoxins, and these toxins cause tissue necrosis with enzymes that degrade the cell wall (Ahmad & Sinha, 2002; Guo et al., 2019). The pathogen is usually carried by water, insects,

agricultural equipment, and infected seeds. This pathogen's spores can enter the plant's leaves, stems, and fruits (Tsuge et al., 2013). Early blight caused by *A. solani* Sorauer is an economically important and widely distributed worldwide disease on crops belonging to the Solanaceae family (Marak et al., 2014). The disease occurs on leaves, stems, petioles, and fruits in high humidity and temperature areas. The pathogen prefers mature tissues and is more frequent during the fruiting period, causing high economic losses (Foolad et al., 2000; Chaerani & Voorrips, 2006). Early blight causes 50% to 80% yield loss, especially in tomato production (Pandey et al., 2020).

Alternaria species have a wide host range, extreme variability, and a long and active vegetative phase, and are very difficult to control (Sharma et al., 2021). Various methods such as crop rotation, resistant varieties, soil fumigation, and fungicide application control the disease (Namanda et al., 2004; Kirk et al., 2005). Synthetic fungicides, used as both seed and spray treatments, include Captan, Ridomil, Strobilurin, Iprodione, Mancozeb, Carbendazim, Chlorothalonil (Swart et al., 1998; Khan et al., 2007; Horsfield et al., 2010; Karuna et al., 2012; Kumar et al., 2013). However, synthetic fungicides accumulate in soil, animals, and plants and negatively affect the ecosystem. Additionally, fungal agents become resistant to fungicides after a certain period and their combat effectiveness decreases (Smith, 2001). In this context, it has become necessary to research and develop alternative methods to chemicals that are friendly to human health and nature, in the control against fungal disease agents (Soylu et al., 2022).

Essential oils (EOs) obtained from different medicinal and aromatic plants, which do not contain chemicals, stand out as natural fungicides in the control against plant pathogens (Paulitz & Belanger, 2001). PEOs containing sesquiterpenes, monoterpenes, and oxygenated compounds have an antimicrobial effect (Regnault-Roger et al., 2012). These compounds cause the separation of lipid layers from the fungal cell membrane, disruption of cell membrane integrity and permeability by changing membrane structures, and metabolic deterioration in cytoplasmic and mitochondrial structures (Feng & Zheng, 2007; Nerio et al., 2010; Tian et al., 2012). Several studies have highlighted the importance of many plant families i.e. Asteraceae, Liliaceae, Apocynaceae, Apiaceae, Caesalpinaceae, Rutaceae, Piperaceae, Sapotaceae, etc., used as medicinal plants (Sheetal and Singh, 2008). Researchers have reported that different PEOs have antifungal effects against *Alternaria* species. (Feng & Zeng, 2007; Hadizadeh et al., 2009; Feng et al., 2011; Bayan et al., 2017; Moumni et al., 2021; Grati Affes et al., 2023; Porcino et al., 2023).

This study aimed was to evaluate the inhibitory effect of black cumin, cumin, chamomile, cedarwood, and ginger PEOs to control two species of *Alternaria* under *in vitro* conditions.

MATERIALS AND METHODS

Fungal isolates

In the experiment, highly pathogenic fungal isolates of *A. solani* (ET 66) and *A. alternata* (LAa 21) with known virulence and isolated from tomato and cabbage were obtained from the collection of fungal culture at Atatürk University of Agriculture Faculty, Department of Plant Protection and collection of fungal culture at Mustafa Kemal University of Agriculture Faculty, Department of Plant Protection, respectively (Camlica & Tozlu, 2019; Soylu et al., 2024). Fungal isolates were aseptically subcultured and purified by serial transfers onto Petri plates containing 25 mL of potato dextrose agar (PDA-Difco). Plates were incubated in the dark at 25±1°C for 7 days and culture was stored at +4°C in the refrigerator. *Alternaria* culture was prepared for the experiment and was left to grow in the dark at 25±1°C for 7 days in an incubation chamber before being used *in vitro* experiment.

Plant essential oils

PEOs used in this study were black cumin, cumin, chamomile, cedarwood, and ginger (Table 1). PEOs were obtained from Arpaş Arifoğlu Co. (İstanbul, Türkiye). PEOs were stored in sealed glass bottles at +4°C until further use (Amini et al., 2012).

Table 1. List of PEOs used in the study.

Scientific name	Family	English name	Brand name	Purity level (%)
Nigella sativa	Ranunculaceae	Black Cumin	Black Cumin Oil	100
Cuminum cyminum	Apiaceae	Cumin	Cumin Oil	100
Matricaria chamomilla	Asteraceae	Chamomile	Chamomile Oil	100
Cedrus atlantica	Pinaceae	Cedarwood	Cedarwood oil	100
Zingiber officinale	Zingiberaceae	Ginger	Ginger Oil	100

Chemical analysis and identification of PEO components

Five PEOs were analyzed by Gas Chromatography and Mass Spectrometry (GC-MS) (Shimadzu 2010 SE, Kyoto Japan; Süleyman Demirel University Innovative Technologies Application and Research Center). Compounds of PEOs were identified by a combination of the mass spectrum of the Wiley library (Wiley, New York, NY, USA) and the NIST mass spectral database (Semiz et al., 2016).

In vitro efficacy of PEOs on mycelial growth of Alternaria species

The antifungal effect of PEOs was done by contact phase against *Alternaria* species (Soliman and Badeaa, 2002). In the contact phase, different concentrations (0, 500, 1000, 1500, 2000, and 2500 µL/L) of PEOs were prepared by dissolving them in Tween 20 (1:1) and added to flasks containing molten PDA. The PDA was poured into 90 mm plastic Petri plates (20 mL). A fungal disc (5 mm in diameter) was cut from the edge of 7-day-old cultures of *Alternaria* species grown on PDA and was placed at the center of each Petri plate. The plates without the PEOs were used as control treatment. All Petri plates were incubated at 25±1°C for 10 days. The experiment was carried out in a randomized plot design with three replications. The diameters were measured when fungal mycelium covered one plate in the control treatment to calculate the inhibition effect. The mycelial growth inhibition was calculated by the following formula (Equation 1).

$$\text{Mycelial growth inhibition (\%)} = [(dc-dt) / dc] \times 100 \quad (1)$$

where dc and dt represent the mean diameter of the mycelial growth (mm) of the control and treated fungal isolates (Moumni et al., 2021).

Data analysis

The statistical analyses were accomplished with the JMP IN packet statistic program (SAS Institute, Carry, NC, 13.0 PC version). Analysis of variance (ANOVA) followed by LSMeans Differences Student's test ($P \leq 0.01$) was performed to evaluate differences between studied cases.

RESULTS AND DISCUSSION

Chemical analysis of PEOs

The major identified components of the PEOs of black cumin, cumin, chamomile, cedarwood, and ginger are listed in Table 2. In the study, 69 active components were determined in PEOs by GC-MS analysis. The major compounds in the PEOs of black cumin were Eucalyptol (1,8-cineole) (48.28%), alpha-Pinene (14.78%), beta- Pinene (9.07%), and Cymol (8.41%). Cuminaldehyde (31.44%), gamma-Terpinene (17.79%), beta-Pinene (16.03%), and Cymol (14.73%) were predominant components of cumin PEO. Major components of chamomile PEO belonged to Eucalyptol (1,8-cineole) (46.78%), alpha-Pinene (10.17%), and beta-Pinene (6.34%). Eucalyptol (1,8-cineole) (27.88%), Thujopsene (22.59%), alpha- Cedrene (10.08%), alpha-Pinene (9.33%), and alpha-Cedrol (8.23%) were determined in cedarwood PEO. Major components of ginger PEO belong to Sesquithujene (7-epi) (17.72%), Eucalyptol (1,8-cineole) (16.27%), Limonene (12.72%) and Camphene (12.33%).

Table 2. Chemical compound of PEOs determined by GC-MS analysis.

			Nigella sativa[c]	*Cuminum cyminum*[c]	*Matricaria chamomilla*[c]	*Cedrus atlantica*[c]	*Zingiber officinale*[c]
No	**Compound name**[a]	**LRI**[b]			**% of the oil**		
1	Tricyclene	924	0.77	0.04	0.46	0.41	1.44
2	alpha- Thujene	927	2.40	0.32	0.57	0.55	0.16
3	alpha - Pinene	933	14.78	1.68	10.17	9.33	7.01
4	beta- Fenchene	942	-	-	-	-	0.12
5	Camphene	953	4.77	0.24	3.66	3.07	12.33
6	Sabinene	972	2.23	0.32	1.69	1.28	0.51
7	beta- Pinene	978	9.07	16.03	6.34	5.26	2.11
8	4-Methyl-1-hepten-5-one	986	-		-	-	0.54
9	beta- Myrcene	991	-	0.69	0.75	-	1.55
10	Octanal	1006	-		-	-	0.14
11	Phellandrene	1007	-	0.44	0.18	-	0.39
12	DELTA.3-Carene	1009	-	0.05	0.27	-	0.04
13	alpha- Terpinene	1018	-	0.18	0.45	0.27	0.13
14	Cymol	1025	8.41	14.73	3.72	2.84	1.17
15	Limonene	1030	3.10	1.19	7.53	1.72	12.72
16	Eucalyptol (1,8-cineole)	1052	48.28	1.93	46.78	27.88	16.27
17	gamma-Terpinene	1058	3.36	17.79	2.59	2.21	0.70
18	trans-Sabinene hydrate	1088	0.52	0.03	1.42	0.52	0.20
19	alpha- Terpinolen	1096	-	0.13	-	-	0.28
20	Dimethylstyrene (alpha-para)	1104	-	0.52	-	-	0.65
21	Linalool	1114	-	-	2.91	-	-
22	Chrysanthenone	1133	-	-	0.38	-	-
23	Carveol	1152	-	0.10	4.09	-	-
24	Camphor	1157	2.32	0.09	0.99	1.60	0.87
25	4-Terpineol	1193	-	0.28	-	-	0.18
26	Dimethylbenzylcarbinyl acetate (DMBCA)	1200	-	0.35	-	-	0.62
27	alpha- Terpineol	1207	-	-	0.34	-	-
28	Perilla alcohol	1208	-	0.85	-	-	-
29	Dihydrocarvone	1210	-	0.11	-	-	-
30	p-Allylanisole	1210	-	-	0.85	-	-
31	Z-Citral	1238	-	-	-	-	1.88
32	Cuminaldehyde	1247	-	31.44	-	-	-
33	Carvotanacetone	1260	-	0.33	-	-	-
34	E-Citral	1268	-	-	-	-	2.25
35	Phellandral	1277	-	0.34	-	-	-
36	2-Undecanone	1294	-	-	-	-	0.17
37	2-Caren-10-al	1298	-	6.84	-	-	-
38	1-Phenylpropane-1,3-diol	1302	-	0.89	-	-	-
39	Thymol	1307	-	0.10	-	-	-
40	Carvacrol	1317	-	0.05	-	-	-
41	Citronellyl acetate	1363	-	-	-	-	0.37
42	Eugenol	1372	-	-	3.24	-	-

43	alpha- Copaene	1375	-	-	-	-	0.25
44	gamma- Cadinene	1388	-	0.09	-	-	-
45	Linalyl acetate	1392	-	-	-	-	0.93
46	beta- Elemene	1400	-	-	-	-	0.33
47	alpha- Zingiberene	1414	-	-	-	-	0.09
48	alpha- Cedrene	1414	-	-	-	10.08	-
49	beta- Cedrene	1423	-	-	-	1.47	-
50	Caryophyllene	1428	-	0.12	0.62	-	-
51	Thujopsene	1433	-	-	-	22.59	-
52	Germacrene B	1439	-	-	-	-	0.15
53	Farnesene ((E)-, beta)	1466	-	0.05	-	-	-
54	alpha- Cedrene	1483	-	1.32	-	-	-
55	Germacrene D	1490	-	-	-	-	0.45
56	Curcumene	1491	-	-	-	-	4.30
57	Alloaromadendrene	1503	-	-	-	-	0.52
58	Sesquithujene (7-epi)	1506	-	-	-	-	17.72
59	Cuparene	1515	-	-	-	0.68	-
60	alpha- Farnesene	1517	-	-	-	-	1.40
61	beta- Bisabolene	1519	-	-	-	-	3.80
62	beta- Sesquiphellandrene	1534	-	-	-	-	3.80
63	Carotol	1601	-	0.05	-	-	-
64	alpha- Cedrol	1614	-	-	-	8.23	-
65	Tetracosane	2400	-	0.07	-	-	-
66	Pentacosane	2500	-	0.08	-	-	-
67	Hexacosane	2600	-	0.07	-	-	-
68	Heptacosane	2700	-	0.06	-	-	-
69	Nonacosane	2900	-	0.02	-	-	-
			100	100	100	100	100

[a]Compounds listed in order of their elution, [b]LRI: Linear retention index, [c]GC-MS analysis results are shared in the article of Sağlan et al. (2022).

Differences observed in many studies may relate to different components of PEOs in terms of geographical origin, plant variety, and age, environmental and agronomic conditions, harvesting time, drying and extraction methods, and genetic difference (Yeşil Çeliktaş et al., 2007). The Antibacterial, antifungal, and antioxidant activities of cumin EO are attributed to the presence of Cuminaldehyde compounds (Ghasemi et al., 2019). chamomile EO has broad-spectrum antifungal activity by changing the cell membrane permeability of fungi (Seyedjavadi et al., 2020). Another study conducted indicated that EOs from *M. chamomilla* had moderate to weak effects against the mycelial growth of fungi (EL-Hefny et al., 2019). Many herbal shampoos and natural repellents contain cedarwood EO as an active ingredient (Anderson, 1995). Kačániová et al. (2022), reported that the EOs of cedarwood have significant antifungal activities. In this context, researchers found that Eucalyptol (1,8-cineole), and Thujopsene have high antifungal effects (Morcia et al., 2012; Mukai et al., 2019). Growth inhibition of phytopathogenic fungi was attributed to the presence of phenolic compounds such as Sesquithujene, Eucalyptol (1,8-cineole), and Limonene isolated from *Z. officinale* oil (Rahmah et al., 2013; Ayodele et al., 2018).

Inhibitory effect of PEOs on mycelial growth of *Alternaria* species

The effects of six various concentrations (0, 500,1000, 1500, 2000, and 2500 µl/L) of black cumin, cumin, cedarwood, chamomile, and ginger PEOs were evaluated for their inhibitory effects on *Alternaria* species mycelial growth using the contact phase technique. The inhibitory effect of five PEOs is summarized in Table 3. All of the tested PEOs significantly ($P \leq 0.01$) inhibited the mycelial growth of *A. solani* and *A. alternata* at all concentration levels compared to the control. Depending on the dose increase, each PEO used in the experiment reduced the mycelial development

of *A. solani* and *A. alternata* at different rates. The highest radial growth was found on control plates, while the lowest radial growth was found with 2500 µL/L cumin PEO against *A. solani* (ET 66 isolate) *and A. alternata* (LAa 21 isolate). High-dose (2500 µL/L) application of black cumin PEO showed 65.3% and 72.1% effects on tested *A. solani* and *A. alternata*, respectively. In other doses of black cumin PEO, inhibition of mycelial growth of *A. solani* was between 14.2% and 50.7%, while inhibition of mycelial growth of *A. alternata* was between 26.3% and 61.1%. The highest inhibitory effect in cumin PEO was determined against *A. solani and A. alternata* in the high-dose treatment at 80.3% and 87.6%, respectively, while 2000 µL/L dose application followed the next highest effect (64.5% and 69.5%). In other doses of cumin PEO, inhibition of mycelial growth of *A. solani* was between 17.2% and 64.5%, while inhibition of mycelial growth of *A. alternata* was between 25.0% and 69.5%. The highest antifungal effect in chamomile PEO was found at the rates of 64.1% and 69.4%, respectively, against *A. solani* and *A. alternata* in 2500 µL/L application. PEO of chamomile showed a potent inhibitory effect on the radial growth of *A. solani* (64.1%), *A. alternata* (69.4%) in 2500 µL/L application. In other doses of chamomile PEO, inhibition of mycelial growth of *A. solani* was between 12.8% and 49.7%, while inhibition of mycelial growth of *A. alternata* was between 21.0% and 65.0%. Application of 2500 µL/L in cedarwood PEO had an effect of 70.4% and 74.9% against *A. solani* and *A. alternata* pathogens, respectively. While other doses of cedarwood PEO inhibited the mycelial growth of *A. solani* between 14.6% and 57.8%, it inhibited the mycelial growth of *A. alternata* between 23.0% and 62.0%. While the 2500 µL/L treatment of ginger PEO showed the highest inhibitory effect against *A. solani* (65.1%), this effect was observed to be 70.5% in *A. alternata*. In other doses of ginger PEO, the radial growth of *A. solani* was reduced between 12.8% and 54.4%, while the radial growth of *A. alternata* was reduced between 16.3% and 58.2%. In the study, cumin PEO was determined as the most effective EO inhibiting mycelial growth of *A. solani* and *A. alternata*, compared to black cumin, chamomile, cedarwood and ginger PEOs. High-dose application of cumin PEO showed a higher inhibitory effect against *A. alternata* than *A. solani*, and the inhibitory effects of the other PEOs were found to be close to each other, depending on the *Alternaria* species and dose (Table 3).

In the present study, *N. sativa* EO showed moderate inhibition against *Alternaria* spp. Similar findings have also been reported by Patni et al. (2005) who tested different EO against *Alternaria brassicae* and *A. alternata*, respectively, and found good results in inhibiting the pathogen mycelial growth under *in-vitro* conditions. In the study conducted by Sitara et al. (2008) reported that *N. sativa* EO at 0.15% was significantly inhibition, but, it exhibited no inhibitory effect against *A. alternata*. In our study, *C. cyminum* EO showed the highest inhibitory effect against *A. solani* and *A. alternata*. Similar to our findings, Romagnoli et al. (2010) reported that the antifungal effect of cumin extract on *Alternaria* sp. is 19.6 % and 81.4% for 5 and 20 µL per disc, respectively. In a study performed by Kedia et al. (2014) *C. cyminum* EO showed an inhibitory effect against *Alternaria* sp. at the dose of 0.6 µL/mL concentration. Ghasemi et al. (2019) reported that *C. cyminum* EO has cuminaldehyde (31.44%) content as the main compounds that show antibacterial, antifungal, and antioxidant activities. Contrary to our findings, Mafakheri and Mirghazanfari (2018) reported that cumin EO exhibited a lower antifungal potential against *Alternaria* sp. In the study, *M. chamomilla* EO showed the lowest inhibitory effect compared to the other four essential oils. Sokovi'c and van Griensven (2006) showed that *M. chamomilla* EO has a weak antifungal effect, which is consistent with our results. Another study showed that *M. chamomilla* EO had moderate to weak effects against the growth of fungi (EL-Hefny et al., 2019). The obtained results were in agreement with those of Sazvar et al. (2022) who reported that the growth rate of *A. alternata* using *M. chamomilla* EO at a concentration of 200µL/L did not differ from the control application, but at higher concentration, the difference in the control application was significant. Our results showed that *C. atlantica* EO inhibited *A. solani* and *A. alternata* at varying rates. Similar to our results, Kumar et al. (2020) reported that *Curvularia lunata*, *A. alternata* and *Bipolaris spicifera* were susceptible to *Cedrus deodara* EO and formed different zones of inhibition showing its inhibitory effect. *C. atlantica* EO inhibited the growth of *Alternaria tenuissima* at concentrations of 1/250 and 1/500 (Chauiyakh et al., 2023). Eucalyptol (1,8-cineole) is the main chemical compound of *C. atlantica* EO. The inhibitory effect of Eucalyptol (1,8-cineole) against pathogenic fungi has been proved previously (Naz, 2011). The present findings show that *Z. officinale* EO has an inhibitory effect on the mycelial growth of *A. solani* and *A. alternata*. Consistent with our findings, Rizwana (2015) reported that various concentrations of *Z. officinale* EO had a moderate to high inhibitory effect on the mycelial growth of *A. alternata*.

Table 3. Inhibitory effect of 5 different PEOs on the mycelial growth of *Alternaria* species.

PEOs	Doses (µL/L)	*A. solani* (ET 66 isolate)		*A. alternata* (LAa 21 isolate)	
		Mycelial growth (mm)[1]	Percent inhibition (%)	Mycelial growth (mm)[1]	Percent inhibition (%)
N. sativa	0 (Control)	42.3 a*	0.0	42.4 a	0.0
	500	36.3 b	14.2	31.3 b	26.3
	1000	31.4 c	25.7	24.3 c	42.6
	1500	26.0 d	38.5	21.3 d	49.7
	2000	20.8 e	50.7	16.5 d	61.1
	2500	14.7 f	65.3	11.8 f	72.1
	$CV_{(0.01)}$	1.1		1.5	
C. cyminum	0 (Control)	42.3 a	0.0	42.4 a	0.0
	500	35.0 b	17.2	31.8 b	25.0
	1000	26.3 c	37.7	24.8 c	41.7
	1500	21.0 d	50.3	20.3 d	52.3
	2000	15.0 e	64.5	12.9 e	69.5
	2500	8.3 f	80.3	5.3 f	87.6
	$CV_{(0.01)}$	1.9		2.1	
M. chamomilla	0 (Control)	42.3 a	0.0	42.4 a	0.0
	500	36.8 b	12.8	33.5 b	21.0
	1000	32.3 c	23.7	27.3 c	35.6
	1500	27.1 d	35.9	21.9 d	48.3
	2000	21.3 e	49.7	16.8 e	60.5
	2500	15.2 f	64.1	13.0 f	69.4
	$CV_{(0.01)}$	1.9		2.3	
C. atlantica	0 (Control)	42.3 a	0.0	42.4 a	0.0
	500	36.1 b	14.6	32.7 b	23.0
	1000	31.0 c	26.6	28.3 c	33.4
	1500	22.4 d	46.9	21.6 d	49.1
	2000	17.8 e	57.8	16.1 e	62.0
	2500	12.5 f	70.4	10.7 f	74.9
	$CV_{(0.01)}$	1.6		2.8	
Z. officinale	0 (Control)	42.3 a	0.0	42.4 a	0.0
	500	36.8 b	12.8	35.5 b	16.3
	1000	32.0 c	24.3	29.6 c	30.3
	1500	26.3 d	37.9	24.3 d	42.6
	2000	19.3 e	54.4	17.8 e	58.2
	2500	14.8 f	65.1	12.5 f	70.5
	$CV_{(0.01)}$	1.9		2.0	

[1]The mean mycelial growth of *Alternaria* species was determined 10 days after inoculation. Based on three replicate plates, each observation. *Mean values followed by different letters within the column are significantly different according to the LSD Test (P≤ 0.01). CV: Coefficient of variation.

CONCLUSIONS

The results showed that PEOs of black cumin, cumin, chamomile, cedarwood, and ginger inhibited the mycelial growth of *Alternaria* species under *in vitro* conditions. The inhibitory effect against *Alternaria* species increased depending on the dose of All five EOs. The highest antifungal effect against *A. solani* (ET 66 isolate) and *A. alternata* (LAa 21 isolate) was obtained from high-dose (2500 µL/L) application of cumin PEO. The inhibitory effect of cumin PEO is thought to be due to the compound Cuminaldehyde. The second highest inhibitory effect against *Alternaria* species was detected in cedarwood PEO. The antifungal effect of cedarwood PEO is due to the compound Eucalyptol (1,8-cineole). The lowest inhibitory effect against *Alternaria* species was detected in the high-dose concentration of chamomile PEO. Therefore, cumin PEO can be used for controlling *A. solani*, and *A. alternata* and may be used as alternative control to synthetic chemicals. However, further studies are needed to explain the application time, dose, cost, and mechanism of action of selected PEOs.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article

Author contribution

Oktay Erdoğan: conceptualization; investigation; methodology; data curation funding acquisition; writing-review & editing.

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Abbreviations

ANOVA: Analysis of variance, *A. solani*: *Alternaria solani*, *A. alternata*: *Alternaria alternata*, *N. sativa*: *Nigella sativa*, *C. cyminum*: *Cuminum cyminum*, *M. chamomilla*: *Matricaria chamomilla*, *C. atlantica*: *Cedrus atlantica*, *Z. officinale*: *Zingiber officinale*, GC-MS: Gas chromatography and mass spectrometry, LRI: Linear retention index, LSD: LSMeans Differences Student's test, CV: Coefficient of variation. PDA: Potato dextrose agar, PEOs: Plant Essential Oils, EOs: Essential Oils.

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