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Full Length Article

Biocontrol Efficacy of Essential Oils of Cumin, Basil and Geranium Against *Fusarium* Wilt and Root Rot of Basil

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Abstract

This study aimed to test the biocontrol efficacy of cumin (*Cuminum cyminum* L.), basil (*Ocimum basilicum* L.) and geranium (*Pelargonium graveolens* L.) essential oils, as a safe alternative for wilt and root rot of sweet basil (*O. basilicum*) caused by *Fusarium oxysporum*, *F. solani* and *F. moniliforme*. Results showed that *F. oxysporum* AUN 520 and *F. oxysporum* AUN 524 caused 41% and 35% of basil wilt, respectively. However, *F. solani* AUN 537 and *F. moniliforme* AUN 670 did not cussed any wilt symptoms but caused high degree of root and crown rot of the plants. Results, obtained from the *in vitro* test, approved the efficiency of the three oils in suppression of the growth of the tested fungi. Basil essential oil caused the highest inhibition of the four fungi. The three oils succeeded to protect the basil plants against the phytopathogenic fungi either in pots or under field conditions. *In vivo*, basil essential oil reduced the wilt percentage to 4.3% and 4.6% compared to 31.2% and 40.3% that were caused by *F. oxysporum* AUN 524 and *F. oxysporum* AUN 520, respectively. In addition, this oil involved in reduction of the root and crown rot of the basil plants to 88 to 94% of the infected plants. Under greenhouse conditions, application of basil oil increased the productivity of the treated plants significantly compared to the untreated control. The tested oils showed a promising efficacy in the control of basil root diseases, as well as stimulation of the overall growth and the productivity. For the first time, the results on field scale recommend the application of the essential oils as good alternatives to the chemical fungicides in the control of root diseases of the basil plants.

Keywords: Biological control; Essential oils; *Fusarium*; *Ocimum basilicum*; Root and crown rots; Wilt

Introduction

Basil is the common name for the culinary herb *Ocimum basilicum* L. of the family Lamiaceae (Sakkas and Papadopoulou, 2017). It is used for its culinary qualities as food additive (Chenni *et al.*, 2016) and applied as an antiseptic in medicines as a slight sedative digestive regulator and diuretic. It was used to treat headaches, coughs, infections of respiratory tract and kidney diseases (Duke *et al.*, 2008; Joshi, 2014; Avetisyan *et al.*, 2017). Because of the immense importance of basil, there is a growing interest in its cultivation and production (Joshi, 2014). However, the producers are still suffering from the low yield because of diseases and application of harmful chemicals (Fiori *et al.*, 2000; Hashem *et al.*, 2010). These fungicides have cautioned due to their negative effects on human's health. Many fungicides were approved for their adverse effect on soil ecosystems and limiting the biodiversity of the beneficial microflora (Thomas and Willis, 1998; Alamri *et al.*, 2016). *Fusarium* wilt of basil is a damaging disease causes a great loss in its productivity (Reuveni *et al.*, 2002; Lori *et al.*, 2014). Symptoms varied from moderate stunting to death of the plant and included wilting, defoliation of basal leaves, and dark lesions on stems with vascular discoloration (Elmer *et al.*, 1994). Minuto *et al.* (1994) and Reuveni *et al.* (2002) approved *Fusarium oxysporum* f. spp. *basilicum* as the main pathogen for basil wilt. They mentioned that sweet basil plants are suffering from wilt diseases caused by *Fusarium oxysporum* and a correlation between the loss in plant fresh weight and the progress of disease. Because of medicinal application of basil, it is preferable to grow free from chemicals and pesticides.

Recently, essential oils were introduced as a good biological control mean to control the plant diseases (Hashem *et al.*, 2010; Meluci *et al.*, 2016; Gayed *et al.*, 2017). Also, these were used as antimicrobial and anti-insect agents (Bakkali *et al.*, 2008; Joshi and Badakar, 2012; Chenni *et al.*, 2016). The bioactivity of the essential oils was attributed to their contents of some active compounds such phenols, thymol, carvacrol and eugenol

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(Tongnuanchan and Benjakul, 2014). Most of the studies dealing with the antifungal action of the oils against the phytopathogenic microorganisms were carried out on the laboratory scale. A little information is available about the application and success of these oils in the field. In previous study, the essential oils succeeded to protect the cumin seedlings from *Fusarium* root rot under field conditions (Hashem *et al*., 2010). Thus, the main goal of this study was to evaluate the effectiveness of essential oils of cumin, basil and geranium in the control of root diseases of basil *in vitro*, *in vivo* and *in situ* as a viable alternative to the synthetic chemical fungicides.

Materials and Methods

The Causal Pathogens

Sweet basil plants that having symptoms of either wilt or root rot were obtained from Assiut Governorate, Egypt. The samples were transferred to the laboratory in polyethylene bags. The pathogenic organisms were isolated from the infected roots on potato dextrose agar (PDA) at 25±1°C for 7 days as described by Gamliel *et al.* (1996). The emerged *Fusarium* species were purified on the same medium using single spore isolation technique and were identified following Leslie and Summerell (2006). The identified fusaria were deposited in the culture collection of Botany Department, Assiut University (AUN) under specific number (*Fusarium oxysporum* AUN520, *F. oxysporum* AUN 524, *F. solani* AUN 537 and *F. moniliforme* AUN 670) for further use.

Pathogenicity Test

Pathogenicity test of *Fusarium oxysporum* AUN520, *F. oxysporum* AUN 524, *F. solani* AUN 537 and *F. moniliforme* AUN 670, which were previously isolated from diseased basal plants was approved on the seedlings of basil. The inocula of the pathogens was prepared by growing them on 150 g sterilized barley grains in 500 mL glass bottles at 25°C. The prepared inoculum was added to sterilized clay soil at the rate of 3% in earthen pots (25 cm in diameter). Pots containing 10 kg of the infested soil were watered three days before cultivation, and 5 surface-disinfested basal seedlings were sown in each pot. For each treatment, 5 pots were used. Pots which were filled with the same soil and sterilized barley grains without organisms were used as a control. After 30 days from transplanting, the percentage of the wilted plants was recorded. Then, plants were uprooted and subjected for morphological tests including root and shoot weight, plant and branching number (Gamliel *et al.*, 1996). The discoloration degree of the roots was applied to determine the mean disease rating (MDR) according to the disease indices of Pal *et al.* (2001) as the following:

0 = healthy (no discoloration), 1 = 1-25% discoloration of roots, 2= 26–50% discoloration of roots, 3= 51–75% discoloration of roots and 4 = 75–100% discoloration of roots.

Mean disease rating (MDR) = $\sum$ (A0 +B1+C2+D3+E4)/(A+B+C+D+E), Where A, B, C, D, and E, are the number of plants with the disease rating of 0, 1, 2, 3, and 4, respectively (Pal *et al.*, 2001).

In vitro Test

The antifungal effect of the essential oils of cumin, basil and geranium was carried out on the growth of the fungal pathogens was teste in the laboratory using the agar diffusion method as described by Sahin *et al.* (2004). The tested oils were provided by the national company for oil production, Egypt.

Greenhouse Study (*in vivo*)

Earthen pots containing clay soil (10 kg pot^{-1}) were infested with the fungal inocula at the rate of 3% (w/w), and 5 pots were used for each treatment. Basil seedlings were immersed for 5 min in 8% concentration of the oils. Seedlings were immersed in sterile distilled water, which served as the control (Land *et al.*, 2001). Five seedlings per pot were cultivated and watered with equal amounts of water when needed. Morphological parameters including root and shoot weight, plant and branching number were recorded after 30 days from the date of planting according to Pandey and Dubey (1994). The percentage of the wilted plants was recorded. The mean disease rating (MDR) of Pal *et al.* (2001) was applied to determine the disease index of the root and crown rot of the plants. The below equation was applied to determine the percentage of disease reduction (DR).

DR (%) = [(MDR of control- MDR of treatment) / MDR of control] ×100

Field Study (*In situ*)

The field experiments were carried out for two successive seasons using the complete randomized block design trial. The plot was divided into three sections, each of a single row 50 cm wide and the sections were separated by a 1.5 m free area. The basil seedlings were treated individually with cumin, basil and geranium oils. Seedling dressing and soil drench were used as two types of treatment. In the first trail, the basil seedlings were immersed in the desired oil (8% v/v) for 15 min. In control, sterile distilled water was used for seedlings immersing. In the second trail, oils (8%, v/v) were added to the soil in the hole of planting (25 mL hole^{-1}). Then the seedlings were transplanted. During the flowering period (at 50 days old), plants were uprooted, and different morphological parameters were assessed including root and shoot weight, plant height, branching, numbers of flowers and production of leaves (Dorrance and McClure, 2001).

Statistical Analysis

To analyze the data statistically, the one-way analysis of variance (ANOVA) and Fisher Multiple Comparison test were applied at P values ≤ 0.05 (Snedecor, 1962).

Results

Pathogenicity Test

Results of the pathogenicity test showed that the four *Fusarium* isolates infect the basil seedling and caused wilt and/or root and crown rot in various degrees, but *F. oxysporum* AUN 520 was the most aggressive one (Table 1). It involved in wilting of 41% of the seedlings and increased the MDR of root and crown rot to 3.5 after 30 days from transplanting. However, *F. oxysporum* AUN 524 involved in wilting of 35% of the basil seedlings and increased the MDR of root and crown rot to 3.4. The results also showed that both *F. solani* AUN 537 and *F. moniliforme* AUN 670 caused root and crown rot symptoms on basil seedlings, however, they did not show any symptoms of wilt. The root and shoot weight, plant height, branches' number were significantly decreased in case of infection with either of the pathogens. The highest reduction in all growth parameters was achieved when the seedlings were infected with *F. oxysporum* AUN 520.

In vitro Antifungal Activity of Essential Oils

Results obtained from the *in vitro* test showed that the three applied oils (cumin, basil and geranium) significantly suppressed the tested *Fusarium* isolates and involved in production of a distinct inhibition zone of growth that varied with the concentration of the applied oil (Table 2). Basil oil showed the widest inhibition zone against the four isolates of *Fusarium*. The increase in fungitoxicity was directly proportional to the increase in concentration of the oil. The widest inhibition zone ranged from 2.2 to 1.7 cm because of application of 8% of the basil oil against *F. oxysporum* AUN 524 and *F. moniliforme* AUN 670, respectively. Cumin oil had nearly a similar pattern against the tested fungi. Its inhibition zone ranged from 1. 7 to 1.9 cm when 8% of cumin oil was used, however geranium oil caused inhibition zone ranged from 1.5 to 1.8 cm, when a dose of 8% of the same oil was applied.

Greenhouse Test (*In vivo*)

Application of the three essential oils significantly reduced both wilt and root and crown rot diseases caused by different isolates of *Fusarium*. Basil oil decreased the wilt of the seedlings to 4.6% and 4.3% in the case of *F. oxysporum* AUN 520 and *F. oxysporum* AUN 524, respectively. This oil reduced the MDR of root and crown rot to 0.2 and reduced the disease by 94.2% in the case of the most aggressive *F. oxysporum* AUN 520. Cumin and geranium oils decreased the disease severity of both wilt and root rot, but in a lower degree than basil oil (Table 3). Data in Table 4 reflect the positive effect of the essential oils application on plant vigor and the productivity. Plant height was increased significantly compared to the control, except in the case of *F. moniliforme* AUN 760. Number of branches was greatly enhanced by the application of the oils to reach 19 branches plant^{-1} in case of basil oil and 18. 7 branches plant^{-1} in the case of cumin oil (Table 4). Fresh weight of the shoots was increased significantly in all treatments of both basil and cumin oils. However, in case of geranium oil, the only significant increase was recorded in case of *F. oxysporum* AUN 524. Basil oil brought about an increase in shoot weight by 90% of the control in case of the same fungus. Root fresh weight had the same positive effect in all cases. The highest increases were approached when the basil oil was applied except in case *F. solani* AUN 537, which showed the highest increase due to application of cumin oil.

Field Study (*In situ*)

The obtained results from field trails were interesting and promising (Table 5). Application of essential oils, either as seed or soil drench, significantly enhanced the growth parameters and the increased the productivity of the basil plants. Basil oil caused the highest increase in all growth parameters when it was applied as a seed dresser. It increased the plant height to 85 cm and the fresh weight to 374 g plant^{-1}. It also increased the fresh weight of root system to 37.5 g plant^{-1} as well as the number of branches and leaves. However, cumin oil was responsible for the highest values of the growth parameters when it was applied as a soil drench. On the other hand, application of essential oils as seed dressing was better than soil drench, and the basil oil treatment showed the best results among the three oils.

Discussion

The result approved the pathogenicity of *F. oxysporum* AUN 520, *F. oxysporum* AUN 524, *F. solani* AUN 537 and *F. moniliforme* AUN 670 on basil seedlings causing wilt and/or root rot diseases. *F. oxysporum* AUN 520 involved in wilting 41% of the basil seedlings. *F. solani* AUN 537 and *F. moniliforme* AUN 670 caused root and crown rot of the basial seedlings. Different *Fusarium* spp. are known as a causal pathogens wilt and root rot diseases of many plants (Persson *et al.*, 1997; Hashem *et al.*, 2010). *Fusarium oxysporum* f. spp. *basilici* is known as the main pathogen of sweet basil wilt, and crown and root rot (Gamliel *et al.*, 1996; Lori *et al.*, 2014). Our results agree with those of Elmer *et al.* (1994), Gamliel *et al.* (1996) and Lori *et al.* (2014), who found that all isolates of *F. oxysporum* were virulent on sweet basil seedlings in the greenhouse.

Table 1: Pathogenicity of four *Fusarium* isolates isolated from diseased basil (*Ocimum basilicum*) plants and their effect on morphogenesis of basil

Fungi	30 days old seedlings					
	Wilt (%)	Root rot (MDR)	Plant height (cm)	Fresh weight (g plant^{-1})	Root fresh weight (g plant^{-1})	No. of branches plant^{-1}
Control (uninfested)	0 c	0.1 c	35.7 a	18.6 a	2.1 a	18.0 a
F. oxysporum AUN 520	41a	3.5 a	29.5 bc	9.5 d	1.2 bc	10.5 c
F. oxysporum AUN 524	35b	3.4 a	28.5 c	13.0 c	1.5 b	12.5 bc
F. solani AUN 537	0 c	3.2 ab	32.0 b	10.8 d	1.0 c	10.7 c
F. moniliforme AUN 670	0 c	3.3 a	37.0 a	16.8 b	1.3 c	13.3 b
LSD $_{0.05}$	2.04	0.20	2.58	1.80	0.38	2.58

MDR = Mean disease rating

Values in the same column followed by the same letter(s) are not significantly different at $P \leq 0.05$

Table 2: *In vitro* antifungal activity of cumin, basil and geranium essential oils in 2, 4 and 8% concentrations expressed as diameter of inhibition zone (in cm) against selected *Fusarium* spp.

Treatments		*F. oxysporum* AUN 520	*F. oxysporum* AUN 524	*F. solani* AUN 537	*F. moniliforme* AUN 670
Control		0.0 g	0.0 d	0.0 e	0.0 b
Cumin oil	2%	0.8 ef	1.0 bc	0.6 d	0.4 b
	4%	1.0 de	1.3 bc	0.8 d	0. 7 ab
	8%	1.8 a	1.9 a	1.8 ab	1.7 a
Basil oil	2%	0.9 e	1.4 bc	1.5 b	0.7 ab
	4%	1.1 cd	1.6 abc	1.8 ab	1.0 ab
	8%	1.9 a	2.2 a	2.1 a	1.7 a
Geranium oil	2%	1.0 d	1.1 bc	0.8 d	0.7 ab
	4%	1.2 c	1.5 bc	1.4 c	1.5 a
	8%	1.5 b	1.8 ab	1.7 b	1.6 a
LSD $_{0.05}$		0.17	0.61	0.33	1.12

Values in the same column followed by the same letter(s) are not significantly different at $P \leq 0.05$

Table 3: Efficacy of cumin, basil and geranium oils (8%) in the control of root rot disease of basil (*Ocimum basilicum* L.) caused by *Fusarium* isolates. *In vivo* after 30 days from transplanting

Fungi	Control		Cumin oil			Basil oil			Geranium oil		
	Wilt%	MDR	Wilt%	MDR	%DR	Wilt%	MDR	%DR	Wilt%	MDR	%DR
F. oxysporum AUN 520	40 a	3.5 a	5.4 a	0.2 c	94.2 a	4.6 a	0.20 d	94.2 a	7.6 a	0.6 a	82.7 a
F. oxysporum AUN 524	31 b	2.6 b	4.5 b	0.3 b	84.2 b	4.3 a	0.23 c	91.9 ab	6.5 a	0.6 a	76.9 b
F. solani AUN 537	0 c	3.1 a	0.0 c	0.2 c	93.6 a	0.0 b	0.40 a	87.9 b	0.0 b	0.6 a	81.8 a
F. moniliforme AUN 670	0 c	3.3 a	0.0 c	0.6 a	82.5 b	0.0 b	0.33 b	89.3 b	0.0 b	0.7 a	67.3 c
LSD $_{0.05}$	2.65	0.65	0.35	0.09	5.26	0.65	0.067	4.23	1.23	0.10	3.69

MDR: Mean disease rating. %DR: Percent disease reduction

Values in the same column followed by the same letter(s) are not significantly different at $P \leq 0.05$

In accordance with our findings, Persson *et al.* (1997) noticed that *F. solani* could not be a causal agent of the vascular wilt, however most *F. oxysporum* isolates caused a significant root rot and wilt. The difference in disease incidence of many isolates, as well as the increase of disease severity for different crops, was mentioned (Hashem *et al.*, 2010; Okoh *et al.*, 2010).

The *in vitro* test approved the efficiency of cumin, basil and geranium essential oils in suppression of the mycelial growth of the fungal pathogens. Basil oil showed the highest antifungal toxicity against the four fungal isolates. The antimicrobial activity of the medicinal plants was previously reported (Okoh *et al.*, 2010; Aguirre *et al.*, 2013; Jhalegar *et al.*, 2015; Kenneth *et al.*, 2017). Our results are supported by those of Piyo *et al.* (2009) and Ali *et al.* (2011), who mentioned that essential oil of two tested basil species inhibited the growth of some phytopathogenic fungi. Farag *et al.* (1989) stated that various essential oils extracted from different plant as well as their basic components involved in the inhibition of the growth of many microorganisms (Meluci *et al.*, 2016). This assumption was also supported by the findings of Sajjadi (2006). Among the main components of the essential oils β-pinene, and terpinolene that were found as major substances of cumin. Methyl chavicol, linalool, epi-α-cadinol, trans-α-bergamotene, geranial, neral and caryophyllene oxide were the main constituents in the basil oil (Sajjadi, 2006; Ali *et al.*, 2011). The antifungal effect of the essential oils was attributed to the mixture of compounds not to any individual component (Falerio *et al.*, 2003).

Under greenhouse conditions, the three essential oils significantly reduced both wilt, and root and crown rot diseases of the basil plants. They also induced the plant vigor and the productivity. The main remark was the three oils were

Table 4: Effect of essential oils of cumin, basil and geranium at 8% concentration as a seedling treatment on growth parameters of basil plants infected with *Fusarium* isolates under greenhouse conditions after 30 days from transplanting

Treatment	*F. oxysporum* AUN 520	*F. oxysporum* AUN 524	*F. solani* AUN 537	*F. moniliforme* AUN 670
Plant height (cm)				
Control	28.5 c	29.5 b	32.0 b	37.0 a
Cu. oil	34.0 b	34.0 a	35.5 a	32.5 c
Ba. oil	36.0 a	35.7 a	35.7 a	34.0 bc
Ge. oil	32.3 b	33.3 a	32.3 b	32.0 c
LSD $_{0.05}$	2.59	3.1	3.07	2.97
Number of branches plant^{-1}				
Control	12.5 d	10.5c	10.7 c	12.5 b
Cu. oil	15.5 bc	13.3 b	14.7 b	18.0 a
Ba. oil	18.7 a	19.0 a	15.5 ab	17.5 a
Ge. oil	14.3 cd	14.7 b	16.5 a	17.7 a
LSD $_{0.05}$	2.04	1.90	2.09	2.21
Root weight (g plant^{-1})				
Control	13.0 b	11.5 b	13.8 b	16.8 bc
Cu. oil	15.5 a	21.1 a	18.6 a	18.3 ab
Ba. oil	16.7 a	22.0 a	17.0 ab	19.2 a
Ge. oil	13.5 b	21.6 a	14.2 b	16.1 c
LSD $_{0.05}$	1.49	3.37	3.90	1.90
Fresh weight (g plant^{-1})				
Control	1.3 a	1.2 b	1.1 a	1.1 c
Cu. oil	1.5 a	1.3 a	1.6 a	1.4 b
Ba. oil	1.5 a	1.5 b	1.5 a	1.5 ab
Ge. oil	1.3 a	1.3 a	1.4 a	1.7 a
LSD $_{0.05}$	0.42	0.20	n.s.	0.21

Cu. oil = Cumin oil., Ba. oil = Basil oil., Ge. oil = Geranium oil
Values in the same column under the same parameter followed by the same letter(s) are not significantly different at $P \leq 0.05$

Table 5: Effect of seedling and soil treatments with essential oils of cumin, basil and geranium at 8% concentration on different growth parameters of basil plants *in situ* after 50 days of cultivation

Treatment	Basil seedling treatment					Soil treatment				
	Plant height (cm)	Plant fresh weight (g pl.$^{-1}$)	Root fresh weight (g pl.$^{-1}$)	No. of br. pl.$^{-1}$	No. of leaves pl.$^{-1}$	Plant height (cm)	Plant fresh weight (g pl.$^{-1}$)	Root fresh weight (g pl.$^{-1}$)	No. of br. pl.$^{-1}$	No. of leaves pl.$^{-1}$
Control	67.5 c	285 b	29.3 c	28.0 c	20.4 d	68.7 b	234 c	24.5 b	25 b	18.9 b
Cu. oil	81.5 ab	360 a	34.6 ab	31.5 b	30.2 c	80.0 a	318 a	29.3 a	30 a	28.5 a
Ba. oil	85.0 a	374 a	37.5 a	33.5 a	32.9 b	75.0 a	309 ab	27.2 ab	28 a	26.1 a
Ge. oil	76.3 b	283 b	32.0 bc	32.0 ab	36.4 a	80.0 a	293 b	29.9 a	28 a	27.3 a
LSD $_{0.05}$	6.71	24.30	3.42	2.50	2.68	6.22	21.20	3.39	2.94	3.59

Cu. oil = Cumin oil., Ba. oil = Basil oil., Ge. oil = Geranium oil, pl. = plant, br. = branch
Values in the same column followed by the same letter(s) are not significantly different at $P \leq 0.05$

effective in control of wilt and/or root and crown rot of the basil plants but in different degrees. The variation of fungicidal effect of the essential oils could be due to the variation and concentration of the chemical components (Farag *et al.*, 1989; Basilico and Basilico, 1999; Meluci *et al.*, 2016). Moreover, Lis-Balchin *et al.* (1999) and Falerio *et al.* (2003) showed that the variation in the effect of the essential oils could be dependent on the type of microbial isolates. Previous studies stated that volatile oils are not very toxic to the fungal spores, but they reduce the spore germination and mycelial growth of many fungi (Basilico and Basilico, 1999). Soliman and Badeaa (2002) reported that spearmint and basil oils effective against *F. moniliforme* and other toxigenic fungi at 300 ppm.

The results of field studies approved the laboratory's and greenhouse findings. The results confirmed the antifungal toxicity of the three essential oils against *Fusarium* spp. Application of essential oils, either as seed dressing or soil drench, significantly enhanced the growth parameters and the increased the productivity of the basil plants, the seed dressing was better than soil drench. Basil essential oil showed the best results among the three applied oils. It was obvious that the three oils had a good biocontrol efficacy against wilt and/or root and crown rot of basil and stimulated its growth and productivity. This could be due to the direct inhibition of the pathogens and the induction of resistance of the plants against the infection (El Ghaouth *et al.*, 2004). Those obtained by Bowers support the present results and Locke (2000), who mentioned that 10% of aqueous extract of chili pepper or cassia tree mixed with essential oil of mustard significantly, reduced *Fusarium* wilt of muskmelon. In this context, Momol *et al.* (2000) mentioned that soil treatment with palmarosa, wild marjoram and thyme oils reduced the tomato root rot in glasshouse.

Previous investigators discussed the mechanism of essential oils as antimicrobial was discussed in many previous papers (Falerio *et al.*, 2003; Sajjadi, 2006; Piyo *et al.*, 2009; Amini *et al.*, 2016). Inouye *et al.* (2000) found that the cell membrane of *Rhizopus stolonifer* could be disrupted by some oils that contain aldehydes. This assumption was confirmed by many others (Tomas-Barberan *et al.*, 1990; Lachowicz *et al.*, 1998; Oxenham *et al.*, 2005; Meluci *et al.*, 2016).

Conclusion

Application of essential oils of basil, cumin and geranium as a seed treatment under field conditions successfully protected the basil crop from root infecting pathogens as well as enhancing the overall growth and the productivity. These findings were supported by the results of pots and laboratory experiments. Therefore, the investigation strongly recommends the application of essential oils, especially those extracted from basil and cumin, in biological control of soil-borne diseases in other crops to approve their efficiency as biological control agents.

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