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Management of disease complex of *Meloidogyne incognita* and *Fusarium oxysporum* f.sp. *radicis lycopersici* on tomato using some essential oils

Domateste *Meloidogyne incognita* ve *Fusarium oxysporum* f.sp. *radicis lycopersici* hastalık kompleksinin bazı esansiyel yağlar kullanılarak yönetimi

Fatma Gül GÖZE ÖZDEMİR[a]*

[a]*Department of Plant Protection, Faculty of Agriculture, Isparta University of Applied Sciences, 32200, Isparta, TURKEY*

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* Corresponding author: Fatma Gül GÖZE ÖZDEMİR
fatmagoze@isparta.edu.tr

A B S T R A C T

The effects of commercial thyme (*Origanum vulgare* L.), sage (*Salvia officinalis* L.), garlic (*Allium sativum* L.), sesame (*Sesame indicum* L.), rosemary (*Rosmarinus officinalis* L., syn. *Salvia rosmarinus* Spenn.), lemon (*Citrus limon* (L.) Osbeck) and mustard (*Brassica nigra* L.) essential oils (Botalife Natural and Aromatic Products Inc., Türkiye) on disease severity were investigated in simultaneous inoculation of *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 and *Fusarium oxysporum* f.sp. *radicis lycopersici* (Jarvis & Shoemaker) (FORL) on tomato. Nematicide (Velum®, Fluopyram, Bayer Crop Production Inc., Türkiye) and fungicide (Cebir®, Fludioxonil + Metalaxyl, Hektaş Crop Production Inc., Türkiye) were used as positive controls. The negative control was only plants with nematode and fungus inoculation. The study was set up in a randomized plot design with 5 replications for each essential oil. In simultaneous inoculations, 1000 *M. incognita* second juvenile larvae/1ml and $3x10^6$ spore/ml FORL were used for each seedling. The essential oil applications were applied to the soil at a dose of 1000 ppm for each pot, one day after the nematode and fungus inoculation. The study was terminated after 60 days, and the evaluation was based on gall, egg mass, and disease severity. Fungal growth and nematode development on roots were found lower in all tested oils applications than in negative control but fungicidal and nematicidal activity varied. Thyme and garlic essential oils had the highest control effect on nematode and fungus with 55.20% in simultaneous inoculation and this effect was higher than only nematicide (38.84%) and only fungicide (33.20%) applications. Sage (38.84%), rosemary (33.28%), and mustard (38.92%) essential oils were found to suppress disease severity higher than sesame (22.16%) and lemon (22.16%). It has been determined that thyme and garlic essential oils are good alternatives to manage root-knot nematode and FORL disease complexes.

INTRODUCTION

Fusarium oxysporum f.sp. *radicis lycopersici* (Jarvis & Shoemaker) (FORL), which causes tomato root rot, is an important pathogen species that causes more than 60% yield loss in the open field and greenhouse tomato production

(Arıcı et al. 2013, Hibar et al. 2007, Manzo et al. 2016, Ozbay et al. 2004). In Turkey, this pathogen was first detected by Can et al. (2004) and it causes significant yield losses in tomato-growing regions (Çolak and Biçici 2013). While it causes stunting and yellowing in tomato seedlings, root rot, wilting and death occur in plants in later periods. Rot in the root area and necrosis in the stem vascular bundles is around 15-30 cm from the soil surface at most (Singh et al. 2022). Although 105 species of root knot nematodes have been reported so far, the most common species in vegetable growing areas in the world and Turkey are *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 (Tylenchida: Meloidogynidae) *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949, *Meloidogyne arenaria* (Neal, 1889) Chitwood, 1949 and *Meloidogyne hapla* Chitwood, 1949 (Adam et al. 2007, Ghaderi and Karssen 2020, Gürkan et al. 2019, Maleita et al. 2021, Uysal et al. 2017). Root-knot nematodes feed on roots and vascular tissues, cause cancer formation, disrupt water and nutrient flow, and show symptoms such as slow growth, yellowing of leaves, wilting, and early plant death in infected plants (Asaturova et al. 2022). *Meloidogyne incognita* and Fusarium disease complexes cause serious losses in horticultural and vegetable crops worldwide (Abuzar and Haseeb 2006, Patil et al. 2021).

In many studies of nematode-fungal disease interactions, pathogens are observed earlier in plants in the presence of nematodes, disease severity increases, and the plant dies completely (Göze Özdemir et al. 2022a, Lobna et al. 2017). Wilt and root rot diseases caused by Fusarium species mostly use resistant cultivars as well as cultivation methods and chemical control programs (Aydın 2019, Bilici et al. 2021). However, cultural methods are insufficient due to the saprophytic viability and the limited development of resistant varieties (Çolak and Biçici 2011, Jiménez-Díaz et al. 2015). In some studies, root-knot nematodes were found to break the plant's resistance even in resistant cultivars developed against Fusarium wilt (Colak-Ates et al. 2018, Göze Özdemir et al. 2022a, Lobna et al. 2016). The general approach to the control of disease complexes formed by root-knot nematodes and fungi is the use of nematicides. However, nematicides are not very effective against both pathogens (Giacometti et al. 2010, Nicolopoulou-Stamati et al. 2016). In addition, the high cost of nematicides, resistance development, health, and environmental hazards, residue, negative effects on soil fauna and beneficial microflora, and phytotoxic effects on plants are the factors limiting their use (Haydock et al. 2013, Silva et al. 2019). A possible alternative to nematicides in the control of nematode-fungal disease complexes is the use of biological agents and plant essential oils (Dutta and Thakur 2017, Türktaş and Koral 2018). Some researchers report that plant essential oils have a broad spectrum activity in controlling bacterial and fungal diseases in many vegetables (Arici et al. 2011, 2013, Bajpai et al. 2009, Shuping and Eloff 2017, Sivakumar and Bautista-Banos 2014). Fungal growth disorders are caused by changes in the structure of fungi associated with the interaction of essential oils on the enzymes responsible for cell wall synthesis (Krzyśko-Łupicka et al. 2020). It has been demonstrated by some studies that isothiocyanates, glucosides, alkaloids, ketones, aldehydes, phenolics, and fatty acids in plants show nematicidal activity (Chitwood 2002, Göze Özdemir et al. 2021, 2022b, Kabera et al. 2014, Stavropoulou et al. 2021). These essential oil components can affect the nematode nervous system as well as disrupt the cell membrane of the nematode and change its permeability (Echeverrigaray et al. 2010, Oka et al. 2000).

The management of disease complexes is more difficult than you suppose. The most effective management is to control one of the interacting organisms and apply appropriate methods to prevent the formation of the disease complex (Abuzar 2012). The effectiveness of essential oils on fungi and nematodes was evaluated separately by researchers and it was found that many of them could be used as an alternative to chemicals. Therefore, it is important to study the effect of essential oils in controlling *M. incognita* and FORL disease complex. This study aims to investigate the effect of thyme (*Origanum vulgare* L.), sage (*Salvia officinalis* L.), garlic (*Allium sativum* L.), sesame (*Sesame indicum* L.) , rosemary (*Rosmarinus officinalis* L., syn. *Salvia rosmarinus* Spenn.), lemon (*Citrus limon* (L.) Osbeck) and mustard (*Brassica nigra* L.) essential oils in the treatment of *M. incognita* and FORL disease complex in tomato.

MATERIALS AND METHODS

Material

The FORL isolate used in this study was isolated from a tomato plant in Antalya / Serik district, and its diagnosis was made according to Gerlach and Nirenberg (1982) and Davis and Raid (2002) (Göze Özdemir et al. 2022a). *Meloidogyne incognita* isolate DR17 was used (Uysal et al. 2017) and whose mass production continues under climate room conditions (24 ± 1 °C, 60% ± 5% humidity). The study was carried out on a tomato cultivar Gulizar F1 which is known to be susceptible to root knot nematode and FORL (Göze Özdemir et al. 2022). Essential oils are commercially available from Botalife Natural and Aromatic Products Inc. (Isparta, Türkiye). Nematicide (Velum®, Fluopyram) and fungicide (Cebir®, Fludioxonil + Metalaxyl) used as positive control were produced by Bayer and Hektaş Crop Protection Inc., respectively.

Method

Preparation of fungal inoculum

FORL isolate was incubated at 25 °C for 7 days in sterile petri dishes (9 cm) containing potato dextrose agar medium (PDA). Then, 5 fungal disc pieces (1 cm^2) were cultured in autoclaved 250 ml flasks containing 50 ml of PDB (potato dextrose brooth agar) and incubated at 25 °C in the dark for 7 days. Handshaking was performed daily during the incubation period. After seven days, the culture filtrate was first filtered through two layers of filter paper (Whatman No. 1) and then refiltered through a 0.45 lm pore-size filter to remove fungal spores and mycelium. The filtrate was kept at +4 °C until the experiment was established (Lobna et al. 2016).

Preparation of nematode inoculum

A thousand second juvenile larvae (J2) of *M. incognita* were used as nematode inoculum. After mass-produced tomato roots of Tueza F1, tomato variety were washed in tap water, egg masses were removed from the roots under a stereo microscope and incubated in water at 25±2 ºC for three days in a petri dish containing a sterile sieve of 3 cm diameter. After three days, the J2s hatched from the eggs were counted under a light microscope and placed in 1 ml tubes, adjusted to the number to be used in the experiment (Lobna et al. 2017).

Effect of some essential oils on Meloidogyne incognita and FORL disease severity on tomato

In this study, the effects of thyme (*O. vulgare*), sage (*S. officinalis*), garlic (*A. sativum*), sesame (*S. indicum*) , rosemary (*R. officinalis*, syn. *S. rosmarinus*), lemon (*C. limon*) and mustard (*B. nigra* L.) essential oils and positive controls of nematicide and fungicide on nematode and fungus in the simultaneous inoculation of *M. incognita* and FORL in Gülizar F1 tomato cultivar were investigated between January and April 2022 in Isparta, Türkiye. Only plants with simultaneous application of *M. incognita* and FORL were evaluated as negative control. The study was set up in a climate room under controlled conditions (24 ± 1 °C, 60% ± 5% humidity) in plastic pots and in a randomized plot design for each essential oil with 5 replications. Three-week-old tomato seedlings were transplanted into plastic pots with a diameter of 14 cm containing approximately 1500 g of sterile, soil (68% sand, 21% silt and 11% clay). In the initial inoculum density per pot, 1000 *M. incognita* J2/1ml and $3x10^6$/10 ml FORL were used and simultaneous inoculation was performed. The nematode inoculum was evenly dispersed with a pipette into three 2-3 cm deep holes drilled around the seedling stem and deep enough to contact the roots in the soil. Fungi inoculation was poured into these holes opened on the soil surface of the pots with the help of a measuring tape (Lobna et al. 2016, 2017). One day after nematode and fungus inoculation, 1000 ppm/pot for each essential oil was applied to the soil (Simsek 2020). The maximum field recommendation doses of Velum and Cebir were used 0.16 ml/l and 0.25 ml/l, respectively.

The study was terminated 60 days after the essential oil applications. Tomato plants related to each application were carefully removed from the soil and their soils were washed with tap water. Evaluation is 1-9 root gall scale for nematodes (1= no gall, 2= 5% root gall, 3= 6-10% root gall, 4= 11-18% root gall, 5= 19-25% root gall, 6= 26-50% root gall, 7= 51-65% root gall, 8= 66-75% root gall, 9= 76-100% root gall) and egg mass production rate scale (1= no egg mass, 2 = 1 or 2 egg masses, 3= 3-6 egg masses, 4= 7-10 egg masses, 5= 11-20 egg masses, 6= 21-30 egg masses, 7= 31-60 egg masses, 8= 61 -100 egg masses, 9= more than 100 egg masses) (Göze Özdemir and Karaman 2020, Mullin et al. 1991). The severity of disease caused by FORL was evaluated according to the 0-4 scale of Chandler and Santelman (1968) (0: No damage to the seedling, 1: Discoloration and small lesions at the junction of the seedling with the soil surface, 2: Larger lesions turned stem, 3: Large lesions surrounding the stem, resulting in a concave appearance, 4: Dead plant due to fungal damage) (Erol and Tunalı 2007). The percentages of suppressing gall, egg mass and disease severity were calculated with the formula % = (nematode alone – treatment/Nematode alone) X100 (Xiang et al. 2020). The mean of the data obtained was compared according to the LSD test ($P \leq 0.05$) using the SAS (version 17.00) program.

RESULTS AND DISCUSSION

In this study, the gall and egg mass index were significantly lower in all essential oil, nematicide and fungicide applications than the negative control application ($P \leq 0.05$). Gall and egg mass index of essential oils were determined to be higher when compared to nematicide while lower than fungicide application. Among the essential oils, the highest gall index was found in sage application with 5.4 and the lowest in thyme application with 3.2 ($P \leq 0.05$). The gall index of garlic (3.8) and mustard (3.6) essential oil applications were lower than sesame (4.6), rosemary (4.2) and lemon (4.2) applications. In garlic, mustard, rosemary and lemon essential oil applications, the suppressive effect on gall was found to be over 50%. The highest suppressive effect on galling was found in thyme essential oil application with 62.4% compared to the negative control ($P \leq 0.05$). Sesame essential oil suppressed galling by 46.4% and its effect was higher than sage. It was observed that the egg mass index were higher than gall index in essential oil applications. It was found that the egg mass index varied between 3.6 and

5.8 in essential oil applications. The suppressive effect on the egg mass was determined above 50% only in mustard (56.78%) and thyme (59.06%) essential oil applications. The suppressive effect on the egg mass of other essential oils used in the study varied between 34-55% (Table 1).

In simultaneous application of *M. incognita* and FORL, the disease severity scale was found to be 3.6. The nematicide (2.2) and fungicide (2.4) applications to the simultaneous *M. incognita* and FORL inoculation significantly reduced the disease scale compared to negative control ($P \leq 0.05$) and suppressed by 33%. In sesame, rosemary, lemon, mustard and sage essential oil applications, the disease scale was in the same statistical group as the fungicide application ($P \geq 0.05$). The disease severity scale was determined as 1.6 in thyme and garlic oil applications. It was found that only two of the seven essential oils (thyme and garlic) suppressed the disease severity by more than 50%. The sage (38.84%), rosemary (33.28%) and mustard (38.92%) essential oils applications were found to suppress disease severity higher than sesame (22.16%) and lemon (22.16%). Except for sesame and lemon oil, the percentage of suppressing disease severity of the other essential oils used in the study was higher than the fungicide application (Table 1).

The suppressive effect of the essential oils used in the study on nematode and fungus in tomato was found to be significantly higher when compared to the negative control. It was determined that the application of fungicide in simultaneous inoculations suppressed the FORL and *M. incognita* by 30% compared to the negative control. However, disease severity was suppressed by 40% when nematicide is applied. Since essential oils of sage, sesame, rosemary, lemon and mustard are effective on both organisms in the nematode-disease complex, their suppressive effect on disease severity was included in the same statistical group as fungicide application. Although higher gall and egg mass index were determined in thyme and garlic essential oil applications than nematicide application, these 2 essential oils showed a higher suppressive effect on disease severity than nematicide and fungicide applications. These results show that applications that are effective on both organisms are more successful in the control against *M. incognita*-FORL disease complex. In additionit, it represents that nematode management is important while controlling the disease complex, and it also reveals that it should be a priority. This is due to plant parasitic that nematodes can cause various lesions in the roots of the host plant that facilitate infection of fungal hyphae, or cause physiological

Table 1. Effect of some essential oils on *Meloidogyne incognita* and *Fusarium oxysporum* f.sp. *radicis lycopersici* (FORL) disease severity on tomato

	LSD test						
	Applications of essential oil	Gall index (1-9)*	Percent suppressive effect on gall (%)	Egg mass index (1-9)**	Percent suppressive effect on egg mass (%)	Disease severity scale***	Percent suppressive effect on disease (%)
1	N+FORL+thyme	3.2 f****	62.74 b	3.6 e	59.06 b	1.6 c	55.52 a
2	N+FORL+sage	5.4 bc	37.16 ef	5.8 b	34.06 e	2.4 b	33.32 b
3	N+FORL+garlic	3.8 def	55.76 bcd	4.4 cd	49.94 cd	1.6 c	55.52 a
4	N+FORL+sesame	4.6 cd	46.44 de	4.4 cd	49.94 cd	2.8 b	22.16 b
5	N+FORL+rosemary	4.2 de	51.10 cd	4.8 c	45.38 d	2.4 b	33.28 b
6	N+FORL+lemon	4.2 de	51.08 cd	4.6 c	47.66 d	2.8 b	22.16 b
7	N+FORL+mustard	3.6 ef	58.08 bc	3.8 de	56.78 bc	2.2 bc	38.92 ab
8	N+FORL+Nematicide (Positive control)	1.4 g	83.66 a	1.4 f	84.04 a	2.2 bc	38.84 ab
9	N+FORL+Fungicide (Positive control)	6.0 b	32.52 f	6.2 b	29.52 e	2.4 b	33.20 b
10	N+FORL (Negative control)	8.6 a	0 g	8.8 a	0 f	3.6 a	0 c
	LSD (5%)	0.83	9.63	0.70	7.70	0.71	18.82
	CV(%)	14.57	15.75	11.45	13.20	23.19	44.24

*Scale of 1-9 root galling index (Muller et al. 1991); 1= no gall, 2= 5% root gall, 3= 6-10% root gall, 4= 11-18% root gall, 5= 19-25% root gall, 6= 26-50% root gall, 7= 51-65% root gall, 8= 66-75% root gall, 9= 76-100% root gall)

**Scale of 1-9 Egg mass index (Muller et al. 1991);1= no egg mass, 2= 1 or 2 egg masses, 3= 3-6 egg masses, 4= 7-10 egg masses, 5= 11-20 egg masses, 6= 21-30 egg masses, 7= 31-60 egg masses, 8= 61-100 egg masses, 9= more than 100 egg masses

*** Scale of 0-4 disease severity (Chandler and Santelman 1968); 0=No damage to the seedling, 1=Discoloration and small lesions at the junction of the seedling with the soil surface, 2= Larger lesions turned stem, 3= Large lesions surrounding the stem, resulting in a concave appearance, 4= Dead plant due to fungal damage).

****Means statistically compared with LSD test at $P \leq 0.05$ significance level.

changes lead to increased root secretions (LaMondia 2003). However, increased number of lateral roots and changes in the chemical composition of root exudates that may attract fungi may increase susceptibility to fungal infection (Back et al. 2002). Fungal infection may result in impaired or reduced host resistance, which can lead to larger nematode populations (Viketoft et al. 2020). According to Göze Özdemir et al. (2022a) determined that disease severity caused by FORL on tomatoes increased in the presence of *M. incognita* and determined that nematode infection was important in the durability of FORL resistance on tomatoes. It has been reported in different studies that simultaneous infection by root-knot nematode and FORL causes more severe damage to the host plant than infection by each pathogen alone (Hajji et al. 2016, McGawely 2001).

The most effectıve essential oils on the nematode and fungus disease complex were found thyme and garlic. It was determined that these two essential oils suppressed the *M. incognita* and FORL by more than 55%. The thyme and garlic essential oils have good performance against both pathogens in their simultaneous disease-complex agents. This fungicidal and nematicidal effect may be due to the secondary metabolites of essential oils. Thymol, carvacrol, linalool, p-cimen, geraniol, borneol monoterpenes are found in the essential oil components of most of the thyme species (Paşa 2019). Thymol is a nematicidal compound that can be found in many plants such as thyme and is highly toxic to root-knot nematodes (Deng et al. 2022). Carvacrol and thymol may act on TA receptors and interrupt a signal cascade of receptors in nematode cells (Lei et al. 2010). Garlic has high antimicrobial and antibacterial activity due to the allicin compound it contains (Khashan et al. 2014, Rahman et al. 2022, Tijjani et al. 2017, Wolde et al. 2018). Diallyl disulfide iswhich are the primary sulfur compounds, can effectively control the occurrence of bean root rot, tomato root-knot nematode, and pepper blight (Avato et al. 2000, Ma et al. 2009). Khairan et al. (2021) found that all garlic extracts in their study contained flavonoids, alkaloids and saponin secondary metabolites and showed that ethyl acetate garlic extracts had the highest nematicidal activity against root-knot nematodes. Galisteo et al. (2022) identified the nematicidal components of garlic oil as diallyl disulfide and diallyl trisulfidine and cited it as an important resource for the development of new nematode control products.

The antifungal effect of thyme essential oil on FORL has been demonstrated by previous studies (Arıcı et al. 2013, Bilici et al. 2021). It has also been reported that thyme essential oil inhibits the development of many pathogens (Aksit et al. 2022, Arıcı et al. 2011, Arıcı and Koç 2021, Koçak and Boyraz 2006). Garlic extracts were inhibit F. *Fusarium oxysporum*, *Botrytis cinerea*, *Phytophthora capsici*, *P. nicotianae* and *Verticillium dahliae* (Hayat et al. 2016, Wang et al. 2019). It was determined that the mortality effect of thyme essential oil on *M. incognita* J2 was higher (El-Gindi et al. 2005). Özdemir and Gözel (2018) reported that 3% and 5% doses of thyme (*Thymus serpyllum*) essential oil used in their study suppressed the *M. incognita* gall and egg mass on the roots. Cetintaş and Yarba (2010) reported that essential oils of rosemary, thyme and peppermint suppress root-knot nematode and that the effect of thyme is higher. Root gall index was found to be low in the applications of thyme essential oil with planting (Göze et al. 2014). It has been determined that the most effective application against *M. incognita* race 2 in sugar beet is 2000 ppm dose application of *Thymus vulgaris* L. essential oil to the soil (Tosun et al. 2018). Garlic methanol extract is found effective against *Aphelenchoides sacchari* in mushrooms and *Aphelenchoides grayi* in carrots (Block 2010). Nematicidal activity of garlic essential oil against *M. incognita* on tomatoes and cucumbers and pine tree nematode *Bursaphelenchus xylophilus* has been reported (Al-Shalaby 2009, El-Saedy et al. 2014, Jardim et al. 2020, Park et al. 2005).

In the present study, it was found that nematode control in nematode and fungal disease complexes is very important and should be a priority. When controlling the nematode disease complex, it was found that the effect of nematicide application on disease severity was higher than fungicide application. Furthermore, mustard essential oil and nematicide had similar effects in controlling disease severity in the nematode and fungal disease complex. The main finding of the study is that thyme and garlic essential oil applications are more effective than chemical nematicide and fungicide applications and other essential oils in the control of nematode and fungus disease complex.

Consequently, thyme (*O. vulgare*) and garlic (*A. sativum*) essential oils were determined as the best alternatives to chemicals for managing root-knot nematode and FORL disease complexes. However, mustard essential oil also looks promising. The application of essential oils to the soil will be an effective alternative control method to reduce pesticide use and increase yield in control of root knot nematode and FORL. It can be seen that thyme and garlic essential oils may be presented as a potential for nematode and disease control in organic farming where fewer control options are available. In addition, it is belived that thyme and garlic essential oils may be effective in nematode interactions with other soil-borne pathogens. However, due to the evaporation nature of essential oils, detailed studies should be conducted for their application under field conditions.

ÖZET

Domateste, ticari kekik (*Origanum vulgare* L.), adaçayı (*Salvia officinalis* L.), sarımsak (*Allium sativum* L.), susam (*Sesame indicum* L.), biberiye (*Rosmarinus officinalis* L., syn. *Salvia rosmarinus* Spenn.), limon (*Citrus limon* (L.) Osbeck) ve hardal (*Brassica nigra* L.) esansiyel yağlarının (Botalife Natural and Aromatic Products Inc., Türkiye) eş zamanlı *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 ve *Fusarium oxysporum* f.sp. *radicis lycopersici* (Jarvis & Shoemaker) (FORL) inokulasyonunda hastalık şiddeti üzerine etkileri araştırılmıştır. Pozitif kontrol olarak nematisit (Velum®, Fluopyram, Bayer Crop Production Inc., Türkiye) ve fungisit (Cebir®, Fludioxonil + Metalaxyl, Hektaş Crop Production Inc., Türkiye) kullanılmıştır. Negatif kontrol sadece nematod ve fungus inokulasyonu yapılan bitkilerden oluşmuştur. Çalışma, her bir uçucu yağ için 5 tekerrürlü tesadüf parselleri deneme deseninde kurulmuştur. Eş zamanlı inokulasyonlarda her bir fide için 1000 *M. incognita* ikinci dönem larva/1ml ve 3x10^6 spor/ml FORL kullanılmıştır. Uçucu yağ uygulamaları, nematod ve fungus inokulasyonundan bir gün sonra her saksı için 1000 ppm dozunda toprağa uygulanmıştır. Çalışma 60 gün sonra sonlandırılmış ve değerlendirme gal, yumurta paketi ve hastalık şiddetine göre yapılmıştır. Köklerde fungus büyümesi ve nematod gelişimi, test edilen tüm yağ uygulamalarında negatif kontrole göre daha düşük bulunmuştur, ancak fungus gelişimi ve nematod aktivitesi değişiklik göstermiştir. Kekik ve sarımsak uçucu yağları eş zamanlı inokulasyonda nematod ve fungus üzerinde %55.20 ile en yüksek kontrol etkisine sahip olmuş ve bu etki sadece nematod (%38.84) ve sadece fungisit (%33.20) uygulamalarından daha yüksek bulunmuştur. Adaçayı (%38.84), biberiye (%33.28) ve hardal (%38.92) esansiyel yağlarının, susam (%22.16) ve limona (%22.16) göre hastalık şiddetini daha fazla baskıladığı bulunmuştur. Kekik ve sarımsak esansiyel yağlarının kök ur nematodu ve FORL hastalık komplekslerini yönetmek için iyi birer alternatif olduğu belirlenmiştir.

Anahtar kelimeler: hastalık kompleksi, uçucu yağ, sarımsak, kök ur nematodu, kekik

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