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Original article (Orijinal araştırma)

Suppressive effect of seed powders of some Brassicaceae plants on *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949 (Tylenchida: Meloidogynidae) in tomato and cucumber

Bazı Brassicaceae bitkilerinin tohum unlarının domates ve hıyarda *Meloidogyne incognita (*Kofoid & White, 1919) Chitwood, 1949 (Tylenchida: Meloidogynidae)'ya karşı baskılayıcı etkisi

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Abstract

The aim of the study was to investigate suppressive effect of powdered seeds of *Raphanus sativus* L. (red radish), *Lepidium sativum* L. (cress) and *Eruca vesicaria* (L.) Cav. (arugula) (Brassicales: Brassicaceae) on *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949 (Tylenchida: Meloidogynidae) in tomato and cucumber. This study was conducted under controlled conditions between January and April in 2022. The experiment consisted of 14 treatments of seed powders singly, or in double or triple combinations. Nematode inoculation was made with 1 000 J2 one week following the transplanting of tomatoes and cucumbers into pots. The seed powders were mixed with the soil three days after the nematode inoculation. The root gall and egg mass were evaluated on a scale of 1-9 and the percent control effect was calculated 60 days after treatment. The highest control effect on gall and egg mass (70%) was with a triple powder treatment which consisting of radish (2 g/plant) + cress (2 g/plant) + arugula (2 g/plant) on tomato and cucumber. The control effect of double powder treatments on gall and egg masses were above 55% in tomato and cucumber. The control effect of radish (6 g/plant) in both host plants was found to be similar to double powder treatments which arugula (2 g/plant) + radish (2 g/plant), and cress (2 g/plant) + radish (2 g/plant). In single treatments, the highest control effect was obtained with radish (6 g/plant). In double powder treatments, those containing radish were found to be more effective against *M. incognita*. It was concluded that treatment with radish seed powder against *M. incognita* was more successful than with cress and arugula powders.

Keywords: Brassicaceae, nematicidal effect, red radish, seed powder

Öz

Bu çalışmanın amacı, *Raphanus sativus* L. (kırmızı turp), *Lepidium sativum* L. (tere) ve *Eruca vesicaria* (L.) Cav. (roka) (Brassicales: Brassicaceae)'nın toz haline getirilmiş tohumlarının domates ve salatalıkta *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949 (Tylenchida: Meloidogynidae) üzerindeki baskılayıcı etkinliğinin araştırılmasıdır. Çalışma, 2022 yılı Ocak-Nisan ayları arasında kontrollü koşullarda yürütülmüştür. Çalışma, bitkilerin tohum unlarının tekli, ikili ve üçlü olmak üzere 14 uygulamasından oluşmaktadır. Domates ve salatalıkların saksılara dikilmesinden bir hafta sonra 1 000 J2 ile nematod aşılaması yapılmıştır. Tohum unları, nematod aşılamasından üç gün sonra toprakla karıştırılmıştır. Uygulamadan altmış gün sonra, köklerdeki ur ve yumurta paketi 1-9 skalasına göre değerlendirilmiştir ve yüzde kontrol etki değerleri hesaplanmıştır. Gal ve yumurta paketi üzerinde en yüksek baskılayıcı etki domates ve hıyarda turp (2 g/bitki) + tere (2 g/bitki) + roka (2 g/bitki) üçlü uygulamasında saptanmıştır. İkili uygulamaların gal ve yumurta paketi üzerindeki kontrol etkisi, domates ve hıyarda %55'in üzerinde bulunmuştur. Her iki bitkide de tek başına 6 g/bitki turp tohum unu uygulamasının kontrol etkisinin, roka (2 g/bitki) + turp (2 g/bitki) ve tere (2 g/bitki) + turp (2 g/bitki) ikili uygulamaları ile benzer olduğu bulunmuştur. Tekli uygulamada en yüksek kontrol etki 6 g/bitki ile turp tohumu unundan elde edilmiştir. İkili uygulamalarda turp içerenlerin *M. incognita* üzerinde daha etkili olduğu bulunmuştur. *Meloidogyne incognita* üzerinde turp tohum unu uygulamasının tere ve rokaya göre daha başarılı kontrol sağladığı belirlenmiştir.

Anahtar sözcükler: Brassicaceae, nematisidal etki, kırmızı turp, tohum unu

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Introduction

Tomato and cucumber are among the most important vegetables in terms of the economic value in Türkiye. Türkiye ranks third in the world with tomato production exceeding 12.7 Mt and ranks second in cucumber production with 2 Mt (Arslan et al., 2022). Root-knot nematodes (RKN) are a group of plant parasitic nematodes that cause significant yield losses in tomato and cucumber crops around the world (Sikora & Fernandez, 2005). They feed on roots and vascular tissues, disrupting water and nutrient flow, and cause slow growth, yellowing of leaves, wilting and early plant death of infested plants (Asaturova et al., 2022). Seid et al. (2015) reported that while the product loss due to RKN in different tomato varieties was between 25 and 100%, decrease level of yield in commercial cucumber cultivation was between 12 and 60% (Wehner et al., 1991; Sorribas et al., 1997). It has been reported that they cause 80% yield loss in tomato cultivation in the Western Anatolian Region of Türkiye (Kaşkavalcı, 2007). Although over 100 species of RKN have been described (Ghaderi & Karssen, 2020), *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949, *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949, *Meloidogyne arenaria* (Neal, 1889) Chitwood, 1949, *Meloidogyne chitwoodi* Golden, O'Bannon, Santo & Finley, 1980 and *Meloidogyne hapla* Chitwood, 1949 (Tylenchida: Meloidogynidae) are the most common RKN in vegetable growing areas in Türkiye (Adam et al., 2007; Evlice et al., 2022). *Meloidogyne incognita* is accepted as the most aggressive and important RKN due to its wide host spectrum and high prevalence in the world (Sikora & Fernández, 2005). This species is also common in vegetable growing areas in Türkiye (Çetintaş & Çakmak, 2016; Özarslandan, 2016; Uysal et al., 2017; Gürkan et al., 2019; Aslan & Elekcioğlu, 2022).

Management of RKN is quite expensive and difficult (Asaturova et al., 2022). To reduce the damage caused by nematodes, producers generally apply solarization and use resistant cultivars (Hajihassani et al., 2019). Many synthetic nematicides such as methyl bromide, ethylene dibromide and di-bromochloropropane have been banned due to their carcinogenic effects (Onkendi et al., 2014). 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 limiting factors for their use (Haydock et al., 2013; Silva et al., 2019). Therefore, it has become necessary to search for alternative control methods in the control of plant parasitic nematodes. Plant-based metabolites are perhaps the most intensively researched subject in this area (Pardavella et al., 2020). Nematicidal activity of isothiocyanates, glucosides, alkaloids, ketones, aldehydes, phenolics and fixed fatty acids in plants have been demonstrated (Chitwood, 2002; Kabera et al., 2014; Shalaby et al., 2021; Stavropoulou et al., 2021).

The Brassicaceae is one of the most economically important plant families. When glucosinolate (GLS) compounds in the cell walls of plants of the Brassicaceae family react with myrosin enzyme toxic compounds are produced (Wittstock et al., 2016). As a result of this enzymatic hydrolysis, volatile and biocidal isothiocyanate compounds are produced (Zasada & Ferris, 2004; Ploeg, 2008). Isothiocyanates disrupt the protein structure and precipitate the cell contents (Mennan & Katı, 2010). In Brassicaceae plants, over 100 glucosinolate compounds have been detected, but the most known glucosinolate compounds in vegetables are neoglucobrassicin, glucobrassicanapin and glucobrassicin (Vallejo et al., 2004). Brassica plants can be used as cover or trap plants, and green manures in plant parasitic nematode control (Matthiessen & Kirkegaard, 2006; Schlaeppi et al., 2010). Recently, it seems that studies have mainly focused on Brassicaceae seeds. Brassicaceae seeds were found to have higher glucosinolate levels and were more advantageous due to lower loss of glucosinolate degradation products (Lazzeri et al., 2004). Salem et al. (2012) reported the second stage juvenile (J2) inactivity of *M. incognita* as 95 and 64%, respectively, 72 and 144 h after *Lepidium sativum* L. (Brassicales: Brassicaceae) seed extract application.

Crushing the seeds and using the seed powder have become common in the control of plant parasitic nematodes (Radwan et al., 2012). However, to the best of our knowledge, there is no study on the seed powder applications of Brassicaceae plants as an alternative control method to nematicides and fumigants in Türkiye. In this study, the effectiveness of Brassicaceae family member vegetables in the control of *M. incognita,* which is common in tomato and cucumber growing areas in Türkiye and causes serious economic losses, was evaluated. For this purpose, the suppressive effect of single and combination applications of red radish, *Raphanus sativus* L., cress, *L. sativum* and arugula, *Eruca vesicaria* (L.) Cav. (Brassicales: Brassicaceae) seeds on gall and egg mass formed by *M. incognita* in tomato and cucumber were investigated.

Materials and Methods

Materials

The red radish seed of cv. Cherry Belle, the cress seed of cv. Bahar Gülü and the arugula seed of cv. Derya were obtained from Biotek Seed Company (Konya, Türkiye). *Meloidogyne incognita* isolate DR17 was used (Uysal et al., 2017). The experiment was performed on cucumber cv. Silor F1 and tomato cv. Gülizar F1 susceptible to RKN.

Nematode inoculum

Mass production of *M. incognita* was done in tomato cv. Tueza F1 (Multi Seed) at 24 ± 1°C, 60% ± 5% RH. The tomato seedlings for mass production were transplanted into pots containing sterilized soil (68% sand, 21% silt and 11% clay) and 1 000 J2s were inoculated into the soil. Eight weeks after inoculation, tomato roots were pulled up, carefully washed in tap water and egg masses were collected under a stereomicroscope. The infective J2s from egg masses were hatched in a sterile Petri dish containing water in an oxygenated environment for 3 days and were kept in the refrigerator at 8°C until used. The 1 000 J2s were collected under the light microscope and transferred to Eppendorf tubes for use as inoculum (Lobna et al., 2017).

Preparation of seed powder

One kg of seeds of Cherry Belle, Bahar Gülü and Derya were blended until a fine powder to be applied at 2, 4 and 6 g/plant (Shalaby et al., 2021).

Effect of red radish, cress and arugula seed powder on the development of *Meloidogyne incognita* on tomato and cucumber

The study was conducted between January and April in 2022. This study was conducted under controlled conditions (24 ± 1°C, 60 ± 5% RH) in a completely randomized plot design with 5 replicates of each for the hosts Gülizar F1 tomato and Silor F1 cucumber. Treatments and doses of Brassica plants seed powder used in the experiment are given in Table 1. Plants treated only with *M. incognita* were included as controls.

Table 1. Treatments and doses of brassica plants seed powder used in the experiment

Treatments					
No	Brassica plants	Doses (g/plant)	No	Brassica plants	Doses (g/plant)
1	Arugula	2	8	Red radish	4
2	Arugula	4	9	Red radish	6
3	Arugula	6	10	Cress + arugula	2 + 2
4	Cress	2	11	Cress + red radish	2 + 2
5	Cress	4	12	Arugula + red radish	2 + 2
6	Cress	6	13	Cress + arugula + red radish	2 + 2 + 2
7	Red radish	2	14	Control	only plants treated with *M. incognita*

Gülizar F1 tomato and Silor F1 cucumber seedlings with approximately four true leaves were transplanted into 14-cm plastic pots containing ~1.5 kg of sterilized soil (68% sand, 21% silt and 11% clay). One week later, all pots were inoculated with 1 000 J2s of *M. incognita*. Three days after the nematode inoculation, slits were made around the seedlings with a spatula and seed powders were spread evenly in these slits, mixed with the soil and watered after covering (Shalaby et al., 2021). The experiment was assessed 60 days after nematode inoculation. Tomato and cucumber plants were carefully removed from the soil and their roots were washed with tap water. Evaluation procedure was made on the root gall scale of 1-9 according to Mullin 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; and 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; and 9, more than 100 egg masses) (Bozbuga et al., 2015; Göze Özdemir & Karaman, 2020). The control percentages of seed powders on gall and egg masses were calculated with the formula (Xiang et al., 2020):

$$\text{Control effect (\%)} = (\text{Control} - \text{Treatment} / \text{Control}) \times 100.$$

The averages of the gall and egg mass scale were compared by LSD test ($P \leq 0.05$) using the SAS (version 17.00) program, after arcsin transformation of the percentage control effects of seed powders on gall and egg mass.

Results

Tomato experiment

The highest galling rate was 8.6 in the control treatment. The gall indices of all treatments (1.0-5.6) were significantly lower than the control treatment ($P \leq 0.05$). Among the treatments, the highest gall index was with 2 g/plant cress (5.2) and 2 g/plant arugula (5.6). The lowest gall index (1.0) was in the triple powder treatment (2 g/plant doses of cress, arugula and radish). Gall indices of cress, arugula and radish seed powders at 6 g/plant treatments were 3.8, 3.0 and 1.6, respectively. The gall index was lower in combinations with radish in double powder treatments. The 2 g/plant cress + 2 g/plant arugula treatment of gall indices were higher than 2 g/plant cress + 2 g/plant radish, and 2 g/plant cress + 2 g/plant radish treatments (Table 2).

The percentage change in galling of roots by seed powders alone and combine treatments was between 35 and 70%. The double powder treatments reduced galling of roots by over 60%. The triple powder treatment of 2 g/plant cress + 2 g/plant arugula + 2 g/plant radish had the highest effect reducing galling of roots by 70%. This was followed by 2 g/plant arugula + 2 g/plant radish, and 2 g/plant cress + 2 g/plant radish treatments with 68%. It was determined that 6 g/plant radish treatment reduced galling roots by 65%. The control effects of 2 g/plant and 4 g/plant cress treatments, 2 g/plant arugula, and 2 g/plant radish treatments on galling roots were below 50% (Table 2).

Egg masses indices of the treatments varied between 1.0 and 5.8 and were found to be statistically significantly lower than the control treatment (9.0) ($P \leq 0.05$). The highest egg masses index was determined in the treatment of 2 g/plant seed powder of cress (5.8) and arugula (6.0) after then control. The lowest egg masses index was with 2 g/plant cress + 2 g/plant arugula + 2 g/plant radish triple powder treatment (1.0) and in double powder treatments of 2 g/plant arugula + 2 g/plant radish (1.2) and 2 g/plant cress + 2 g/plant radish (1.2). Egg masses index of 2.6 with 2 g/plant cress + 2 g/plant arugula seed powder treatment was higher than other double powder treatments. Egg masses indices of 6 g/plant cress, arugula and radish treatments were determined as 4.2, 3.6 and 2.0, respectively (Table 2).

Radish seed powder treatment at a dose of 2 g/plant decreased the egg masses formed by *M. incognita* on tomato root by 40.5%, while treatments of 4 and 6 g/plant decreased it by 52.2% and 61.9%, respectively. The control effect of 2 and 4 g/plant seed powder treatments of cress and arugula on the egg mass was below 45% whereas the control effect was above 45% in 6 g/plant treatments. The effects of radish 6 g/plant (61.9%) and 2 g/plant cress + 2 g/plant arugula (57.5%) seed powder treatments on egg mass in tomato roots were found as similar. It was determined that control effect in the same statistical group (a) in double powder treatments of 2 g/plant cress + 2 g/plant radish with 2 g/plant arugula + 2 g/plant radish and in triple powder treatments (2 g cress + 2 g arugula + 2 g radish) (Table 2).

Table 2. Effect of cress, arugula, radish plant seed powder against *Meloidogyne incognita* in tomato under controlled conditions

Treatments (plant seed powder)	Root galling index[1]		Percent effect on root galling[4]		Egg mass index[2]		Percent effect on egg masses[4]	
2 g Cress	5.2	cb[3]	39	fe	5.8	b	36	hg
4 g Cress	4.4	cd	44	de	5.2	cb	40	fg
6 g Cress	3.8	ed	48	dc	4.2	ed	47	de
2 g Arugula	5.6	b	36	f	6.0	b	35	h
4 g Arugula	3.8	ed	48	dc	4.6	cd	44	fe
6 g Arugula	3.0	e	54	c	3.6	e	51	d
2 g Radish	4.8	cb	42	fe	5.2	cb	40	fg
4 g Radish	3.0	e	54	c	3.4	e	52	cd
6 g Radish	1.6	gf	65	ba	2.0	gf	62	b
2 g Cress + 2 g arugula	2.0	f	61	b	2.6	f	58	bc
2 g Cress + 2 g radish	1.2	gf	68	a	1.2	gh	69	a
2 g Arugula + 2 g radish	1.2	gf	68	a	1.2	gh	69	a
2 g Cress + 2 g arugula + 2 g radish	1.0	g	70	a	1.0	h	70	a
Untreated Control	8.6	a	0	g	9.0	a	0	ı
LSD (%5)	0.85		6.1		0.78		5.4	
CV (%)	19.2		9.6		15.8		8.8	

[1] Scale of 1-9 root galling index; 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; and 9, 76-100% root gall (Muller et al 1991);
[2] Scale of 1-9 egg mass index;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; and 9, more than 100 egg masses (Muller et al 1991);
[3] Means were compared by LSD test at P ≤ 0.05 and those followed by the same letter within columns are not significantly different.
[4] Arcsin transformation was applied before analysis.

Cucumber experiment

The gall indices for cucumber roots decreased with increasing dose in single treatments with the three seed powders. The effects of combined treatments were greater than in the single powder treatments. The lowest gall index was found 1.0 in the triple powder treatment (2 g/plant cress + 2 g/plant arugula + 2 g/plant radish). There was no difference (P ≥ 0.05) between the gall indices of cress (2 g/plant) + arugula (2 g/plant), arugula (2 g/plant) + radish (2 g/plant), and cress (2 g/plant) + radish (2 g/plant) treatments. Although, the gall index was 1.8 with 6 g/plant red radish, this was lower than the same dose of cress and arugula. The highest gall indices in cucumber roots was with 2 g/plant cress (6.0) and arugula (5.8) (Table 3).

The highest control effect on galling was 71% in the triple powder treatment of 2 g/plant cress + 2 g/plant arugula + 2 g/plant radish. Double powder treatments of cress, arugula and radish reduced galling by more than 55% with no statistically significant difference between them (P ≥ 0.05). Doses of 6 g/plant of cress, 4 and 6 g/plant of arugula and red radish reduced galling in the roots by more than 40%. The effect of 6 g/plant red radish was 55%, which was not statistically different from 2 g/plant cress + 2 g/plant arugula (59%), 2 g/plant arugula + 2 g/plant radish (60%) and 2 g/plant cress + 2 g/plant radish (60%) (Table 3).

The lowest egg masses index was 1.4 with the triple powder treatment (2 g/plant cress + 2 g/plant arugula + 2 g/plant radish) (P ≤ 0.05) and the highest egg masses index was 9.0 in the control treatment, followed by about 6 with 2 g/plant cress and arugula. As the dose of the three seed powders increased, the egg mass index decreased. Egg mass indices were similar in double powder treatments (Table 3).

The treatments reduced egg mass formation between 32 and 67%. The greatest effect was in the triple powder treatment of 2 g/plant cress + 2 g/plant arugula + 2 g/plant radish (P ≤ 0.05). The treatments of 2 g/plant cress + 2 g/plant arugula, 2 g/plant arugula + 2 g/plant radish, and 2 g/plant cress + 2 g/plant radish decreased the egg mass formation by 55, 58 and 56%, respectively. The 6 g/plant cress, arugula and red radish treatments reduced egg mass by 44, 51 and 62%, respectively (Table 3).

Table 3. Effect of cress, arugula, radish seed powder against *Meloidogyne incognita* in cucumber under controlled conditions

Treatments (plant seed powder)	Root galling index[1]		Percent effect on root galling[4]		Egg mass index[2]		Percent effect on egg masses[4]	
2 g Cress	6.0	b[3]	35	g	6.4	b	32	g
4 g Cress	5.0	c	42	f	5.4	c	39	ef
6 g Cress	4.0	d	48	e	4.6	d	44	e
2 g Arugula	5.8	b	37	g	6.2	b	34	fg
4 g Arugula	4.0	d	48	e	4.6	d	44	e
6 g Arugula	3.0	ef	55	cd	3.6	e	51	d
2 g Radish	5.4	bc	39	fg	6.0	bc	35	fg
4 g Radish	3.2	e	53	d	3.6	e	51	d
6 g Radish	1.8	g	64	b	2.2	g	62	ab
2 g Cress + 2 g arugula	2.4	fg	59	bc	3.0	ef	55	cd
2 g Cress + 2 g radish	2.2	g	60	b	2.8	fg	56	cd
2 g Arugula + 2 g radish	2.2	g	60	b	2.6	fg	58	bc
2 g Cress + 2 g arugula + 2 g radish	1.0	h	70	a	1.4	h	67	a
Untreated Control	9.0	a	0	h	9.0	a	0	h
LSD (%5)	0.72		5.0		0.79		5.8	
CV (%)	15.6		8.3		14.3		10.2	

[1] Scale of 1-9 root galling index; 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; and 9, 76-100% root gall (Muller et al 1991);
[2] Scale of 1-9 Egg mass index;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; and 9, more than 100 egg masses (Muller et al 1991);
[3] Means were compared by LSD test at P ≤ 0.05 and those followed by the same letter within columns are not significantly different.
[4] Archsin transformation was applied before analysis.

Discussion

In this study, it was found that soil treatment with cress, arugula and red radish seed powders had a significant nematicidal effect on *M. incognita*. This nematicidal effect increased in tomato and cucumber roots as the doses increased in single powder treatments of cress, arugula and red radish seed powders. In single powder treatments, the highest effect was with 6 g/plant powder in both tomato and cucumber. In tomato, 6 g doses of cress, arugula and radish treatments reduced root galling by 48, 54 and 65%, and egg mass formation by 47, 51 and 62%, respectively. In cucumber, 6 g doses of cress, arugula and radish treatments reduced root galling by 48, 55 and 64%, and egg mass formation by 44, 52 and 62%, respectively. The 2 and 4 g doses of cress, arugula and radish powders had much lower nematicidal effects in both plants. In contrast, Shalaby et al. (2021) in their study of peppers infested with *M. incognita*, found that the application of cress and radish seed powder at 2, 4 and 6 g/plant reduced root galling by 78, 84 and 91%, respectivelyand 85, 90 and 95% reductions in egg masses. In the same study, the researchers found that the effect of radish powder reduced root galling at the same doses by 82, 86 and 89%, respectively and egg mass formation of by 82, 89 and 90%. Salem et al. (2012) reported that *M. incognita* gall, egg masses and J2 density in the soil were completely controlled in tomato by mixing cress seed into the soil 1 week after nematode inoculation. Aydınlı et al. (2019) reported that 4% fresh plant aqueous extracts of cress and mint in tomato, and 1% and 2% aqueous extracts of dry arugula plants significantly reduced damage caused by *M. arenaria*.

In present study, radish seed powder at 6 g/plant had a greater nematicidal effect than cress and arugula. Oka (2010) and Radwan et al. (2012) reported that there may be differences in the toxic substances or biocidal contents of dry seed powders added to the soil of different plants and their microbial degradation products. However, it has been suggested that the nematicidal effect of seed powders of allelopathic plants on nematode populations may also be due to the effect of ammonia released from the seeds, independent of the GLS content (Mazzola et al., 2007, 2009). Zasada et al. (2009) found that the pulp of mustard grass, *Brassica juncea* (L.) Czern. (Brassicales: Brassicaceae) seeds had a more nematoxic effect than white mustard, *Sinapis alba* L. (Brassicales: Brassicaceae) and that 2.5% and 10% dry w/w (corresponding to approximately 50 and 200 t/ha at an incorporation depth of 15 cm) would be required for eradication of *M. incognita* and *Pratylenchus penetrans* (Cobb, 1917) Filipjev & Schuurmans Stekhoven, 1941 (Tylenchida: Pratylenchidae), respectively, while *S. alba* is 0.5% for *B. juncea*. According to the results of study, at least 6 g/plant treatment was required for cress and arugula seed powders to have a control effect of more than 45% for *M. incognita* in tomato and cucumber roots, but only 4 g/plant radish seed powder. Radwan et al. (2012) reported that 5 g/kg radish seed powder treatment reduced root galling in tomato by 78%. In addition, it is stated that the radish plant is a very good trap for RKN and has biofumigant properties when applied to the soil as a plant and green manure (Pattison et al., 2006; Melakeberhan et al., 2008). The radish plant secretes glucosinolate into the soil or glucosinolate emerges as a result of the decomposition of plant parts, and then, as a result of the hydrolysis of glucosinolate, isothiocyanates that have biocidal effects on nematodes are formed (Vallejo et al., 2004; Zasada & Ferris, 2004; Sandler et al., 2015). Aydınlı & Mennan (2018) found that in biofumigation plots applied with radish and arugula, the number of gall and egg mass on the roots of tomatoes decreased significantly. Also, growing these 2 plants as a winter crops before susceptible plants would reduce the damage caused by *M. arenaria* and increase crop yield.

It was found that the combined applications of cress, arugula and red radish seeds powder at 2 g/plant had the highest nematicidal effect against *M. incognita* in tomatoes and cucumbers in present study. The control effects of this treatment on gall and egg masses in tomato and cucumber were both about 70%. The control effect of double powder treatments on gall and egg masses in tomato and cucumber were lower than triple powder treatment but significantly higher than the single powder treatments. In tomato and cucumber, the control effect of double powder treatments on gall and egg masses were above 55%. Gall and egg mass index of cress (2 g/plant) + arugula (2 g/plant) treatment in tomato and cucumber roots was found to be higher than arugula (2 g/plant) + radish (2 g/plant) and cress (2 g/plant) + radish (2 g/plant) treatments. The control effect increased in tomato and cucumber roots in double powder treatments with radish. In present study, the highest control effect was found in triple powder treatment of arugula (2 g/plant) + radish (2 g/plant) + cress (2 g/plant). In the study of Zanbouri & Fatemy (2014) with single and combined applications of cress, *L. sativum* and peppermint, *Mentha pulegium* L., 1753 (Lamiaceae: Mentheae), they found that the mean hatching of *Globodera rostochiensis* (Wollenweber, 1923) (Tylenchida: Heteroderidae) to be both about 0.5%, and J2 activity was blocked by 97% after 24 h in both plant extracts. Unlike the Brassicaceae, Asif et al. (2016) reported that in the application of wild spinach (Amaranthaceae) seed powder with freshly chopped leaves of different plants, *M. incognita* was significantly suppressed compared to the control.

Consequently, differences were determined in the nematicidal activity of cress, arugula and radish seeds against *M. incognita* in tomato and cucumber under controlled conditions. Radish seed powder was found to be the most effective treatment. However, combined treatments of radish, cress and arugula seed powders successfully suppressed RKN even at low doses. As a result, plants belonging to Brassicaceae are thought to be a good alternative to chemicals both in biofumigation, with their extracts and due to the potential nematicidal and nematostatic effects contained in their seeds, and they should be supported by detailed studies in field conditions.

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References

Adam, M. A. M., M. S. Phillips & V. C. Blok, 2007. Molecular diagnostic key for identification of single juveniles of seven common and economically important species of root-knot nematode (*Meloidogyne* spp.). Plant Pathology, 56 (1): 190-197.

Arslan, Ş., H. Arısoy & Z. Karakayacı, 2022. The situation of regional concentration of tomato foreign trade in Turkey. Turkish Journal of Agriculture-Food Science & Technology, 10 (2): 280-289.

Asaturova, A. M., L. N. Bugaeva, A. I. Homyak, G. A. Slobodyanyuk, E. V. Kashutina, L. V. Yasyuk & A. V. Garkovenko, 2022. *Bacillus velezensis* strains for protecting cucumber plants from root-knot nematode *Meloidogyne incognita* in a greenhouse. Plants, 11 (3): 275-291.

Asif, M., A. Khan, M. Tariq & M. A. Siddiqui, 2016. Sustainable management of root knot nematode *Meloidogyne incognita* through organic amendment on *Solanum lycopersicum* L. Asian Journal of Biology, 1 (1): 1-8.

Aslan, A. & İ. H. Elekcioğlu, 2022. Biochemical and molecular identification of root-knot nematodes in greenhouse vegetable areas of Eastern Mediterranean Region (Turkey). Turkish Journal of Entomology, 46 (19): 115-127.

Aydınlı, G. & S. Mennan, 2018. Biofumigation studies by using *Raphanus sativus* and *Eruca sativa* as a winter cycle crops to control root-knot nematodes. Brazilian Archives of Biology & Technology, 61 (e18180249): 1-9.

Aydınlı, G., F. Şen & S. Mennan, 2019. Potential of some plant extracts for the control of root-knot nematode *Meloidogyne arenaria* (Neal, 1889) Chitwood, 1949 (Tylenchida: Meloidogynidae). KSU Journal of Agriculture & Nature, 22 (3): 414-420.

Bozbuga, R., H. Y. Dasgan, Y. Akhoundnejad, M. Imren, H. Toktay & E. B. Kasapoglu, 2015. Identification of common bean (*Phaseolus vulgaris*) genotypes having resistance against root knot nematode *Meloidogyne incognita*. Legume Research-An International Journal, 38 (5): 669-674.

Çetintaş, R. & B. Çakmak, 2016. *Meloidogyne* species infesting tomatoes, cucumbers and eggplants grown in Kahramanmaraş Province, Turkey. Turkish Journal of Entomology, 40 (4): 355-364.

Chitwood, D. J., 2002. Phytochemical based strategies for nematode control. Annual Review of Phytopathology, 40 (1): 221-249.

Evlice, E., H. Toktay, G. Yatkın, F. D. Erdoğuş & M. İmren, 2022. Population fluctuations of root-knot nematodes *Meloidogyne chitwoodi* and *M. hapla* under field conditions. Phytoparasitica, 50 (1): 233-242.

Ghaderi, R. & G. Karssen, 2020. An updated checklist of *Meloidogyne* Göldi, 1887 species, with a diagnostic compendium for second-stage juveniles and males. Journal of Crop Protection, 9 (2): 183-193.

Göze Özdemir, F. G. & R. Karaman, 2020. The reaction of some mung bean (*Vigna radiata* Wilczek) genotypes with *Meloidogyne incognita* race 2. Turkish Journal of Agricultural Research, 7 (3): 274-279.

Gürkan, B., R. Çetintaş & T. Gürkan, 2019. Determination of root-nematode species (*Meloidogyne* spp.) and some nematode population races in vegetable areas of Gaziantep and Osmaniye. KSU Journal of Agriculture and Nature, 22 (Suppl 1): 113-124.

Hajihassani, A., R. F. Davis & P. Timper, 2019. Evaluation of selected nonfumigant nematicides on increasing inoculation densities of *Meloidogyne incognita* on cucumber. Plant Disease, 103 (12): 3161-3165.

Haydock, P. J., S. R., Woods & I. G. Grove, 2013. "Chemical Control of Nematodes, 459-479''. In: Plant Nematology (Eds. R. N. Perry & M. Moens). CAB International, Wallingford, 568 pp.

Kabera, J. N., E. Semana, A. R. Mussa & X. He, 2014. Plant secondary metabolites: biosynthesis, classification, function and pharmacological properties. Journal of Pharmacy & Pharmacology, 2 (7): 377-392.

Kaşkavalcı, G., 2007. Effects of soil solarization and organic amendment treatments for controlling *Meloidogyne incognita* in tomato cultivars in western Anatolia. Turkish Journal of Agriculture and Forestry, 31 (3): 159-167.

Lazzeri, L., G. Curto, O. Leoni & E. Dallavalle, 2004. Effects of glucosinolates and their enzymatic hydrolysis products via myrosinase on the root-knot nematode *Meloidogyne incognita* (Kofoid et White) Chitw. Journal of Agricultural & Food Chemistry, 52 (22): 6703-6707.

Lobna, H., E. M. Aymen, R. Hajer, M. Naima & H. R. Najet, 2017. Biochemical and plant nutrient alterations induced by *Meloidogyne javanica* and *Fusarium oxysporum* f. sp. *radicis lycopersici* co-infection on tomato cultivars with differing level of resistance to *M. javanica*. European Journal of Plant Pathology, 148 (2): 463-472.

Matthiessen, J. N. & J. A. Kirkegaard, 2006. Biofumigation and enhanced biodegradation: opportunity and challenge in soilborne pest and disease management. Critical Reviews in Plant Sciences, 25 (3): 235-265.

Mazzola, M., J. Brown, A. D. Izzo & M. F. Cohen, 2007. Mechanism of action and efficacy of seed meal-induced pathogen suppression differ in a *Brassicaceae* species and time-dependent manner. Phytopathology, 97 (4): 454-460.

Mazzola, M., J. Brown, X. Zhao, A. D. Izzo & G. Fazio, 2009. Interaction of *brassicaceous* seed meal and apple rootstock on recovery of *Pythium* spp. and *Pratylenchus penetrans* from roots grown in replant soils. Plant Disease, 93 (1): 51-57.

Melakeberhan, H., S. Mennan, M. Ngouajio & T. Dudek, 2008. Effect of *Meloidogyne hapla* on multi-purpose use of oilseed radish (*Raphanus sativus*). Nematology, 10 (3): 375-379.

Mennan, S. & T. Katı, 2010. Biofumigation for control of plant parasitic nematodes. Anadolu Journal of Agricultural Sciences, 25 (2): 120-134.

Mullin, B. A., G. S. Abawi, M. A. Pastor-Corrales & J. L. Kornegay, 1991. Reactions of selected bean pure lines and accessions to *Meloidogyne* species. Plant Disease, 75: 1212-1216.

Oka, Y., 2010. Mechanisms of nematode suppression by organic soil amendments-a review. Applied Soil Ecology, 44 (2): 101-115.

Onkendi, E. M., G. M. Kariuki, M. Marais & L. N. Moleleki, 2014. The threat of root-knot nematodes (*Meloidogyne* spp.) in Africa: a review. Plant Pathology, 63 (4): 727-737.

Özarslandan, A., 2016. Soil disinfestation against root knot nematodes on grown tomatoes in greenhouses. Plant Protection Bulletin, 56 (4): 407-416.

Pardavella, I., D. Daferera, T. Tselios, P. Skiada & I. Giannakou, 2020. The use of essential oil and hydrosol extracted from *Cuminum cyminum* seeds for the control of *Meloidogyne incognita* and *Meloidogyne javanica*. Plants, 10 (1): 46-60.

Pattison, A. B., C. Versteeg, S. Akiew & J. Kirkegaard, 2006. Resistance of *Brassicaceae* plants to root-knot nematode (*Meloidogyne* spp.) in northern Australia. International Journal of Pest Management, 52 (1): 53-62.

Ploeg, A., 2008. “Biofumigation to Manage Plant-Parasitic Nematodes, 239-248’’. In: Integrated Management and Biocontrol of Vegetable and Grain Crops Nematodes (Eds. A. Ciancio & K. G. Mukherji). Springer, Dordrecht, 339 pp.

Radwan, M. A., S. A. A Farrag, M. M. Abu-Elamayem & N. S. Ahmed, 2012. Biological control of the root-knot nematode, *Meloidogyne incognita* on tomato using bioproducts of microbial origin. Applied Soil Ecology, 56 (2012): 58-62.

Salem, M. F., G. Y. Osman, S. E. Hasab El-Nabi & F. Khalaf, 2012. Effect of certain medicinal plants natural products on *Meloidogyne incognita* management in vitro. Journal of Plant Protection & Pathology, 3 (10): 1051-1058.

Sandler, L., K. A Nelson & C. J. Dudenhoeffer, 2015. Radish planting date and nitrogen rate for cover crop production and the impact on corn yields in upstate Missouri. Journal of Agricultural Science, 7 (6): 1-13.

Schlaeppi K, E. Abou-Mansour, A. Buchala & F. Mauch, 2010. Disease resistance of Arabidopsis to *Phytophthora brassicae* is established by the sequential action of indole glucosinolates and camalexin. Plant Journal, 62 (5): 840-851.

Seid, A., C. Fininsa, T. Mekete, W. Decraemer & W. M. Wesemael, 2015. Tomato (*Solanum lycopersicum*) and root-knot nematodes (*Meloidogyne* spp.)-a century-old battle. Nematology, 17 (9): 995-1009.

Shalaby, M., S. B. Gad, A. E. Khalil & A. G. El-Sherif, 2021. Nematicidal activity of seed powders of some ornamental plants against *Meloidogyne Incognita* infecting pepper under greenhouse conditions. Journal of Plant Protection and Pathology, 12 (8): 499-506.

Sikora, R. A. & E. Fernández, 2005. ''Nematode Parasites of Vegetables, 319-392''. In: Plant Parasitic Nematodes in Subtropical and Tropical Agriculture (Eds. R. A. Sikora, D. Coyne, J. Hallmann & P. Timper), CABI, USA, 853 pp.

Silva, J. D. O., A. Loffredo, M. R. da Rocha & J. O. Becker, 2019. Efficacy of new nematicides for managing *Meloidogyne incognita* in tomato crop. Journal of Phytopathology, 167 (5): 295-298.

Sorribas Royo, F. J., C. Ornat Longarón & S. Verdejo Lucas, 1997. Effect of the previous crop on population densities of *Meloidogyne javanica* and yield of cucumber. Nematropica, 27 (1): 83-88.

Stavropoulou, E., E. Nasiou, P. Skiada & I. O. Giannakou, 2021. Effects of four terpenes on the mortality of *Ditylenchus dipsaci* (Kühn) Filipjev. European Journal of Plant Pathology, 160 (1): 137-146.

Uysal, G., M. A. Söğüt & İ. H. Elekçioğlu, 2017. Identification and distribution of root-knot nematode species (*Meloidogyne* spp.) in vegetable growing areas of Lakes Region in Turkey. Turkish Journal of Entomology, 41 (1): 105-122.

Vallejo, F., F. A. Tomás-Barberán & F. Ferreres, 2004. Characterization of flavanols in broccoli (*Brassica oleracea* L. var. italica) by liquid chromatography-UV diode-array detection-electrospray ionization mass spectrometry. Journal of Chromatography A, 1054 (1-2): 181-193.

Wehner, T. C., S. A. Walters & K. R. Barker, 1991. Resistance to root-knot nematodes in cucumber and horned cucumber. Journal of Nematology, 23 (4S): 611-614.

Wittstock, U., E. Kurzbach, A. Herfurth, E. Stauber & S. Kopriva, 2016. ''Glucosinolate Breakdown, 125-169''. In: Advances in Botanical Research (Eds. J. C. Kader & M. Delseny). Elseiver, Oxford, U.K., 399 pp.

Xiang, C., Y. Liu, S. M. Liu, Y. F. Huang, L. A. Kong, H. Peng & W. K. Huang, 2020. αβ-Dehydrocurvularin isolated from the fungus *Aspergillus welwitschiae* effectively inhibited the behaviour and development of the root-knot nematode *Meloidogyne graminicola* in rice roots. BMC Microbiology, 20 (1): 1-10.

Zanbouri, B. P. & S. Fatemy, 2014. "Two methods of evaluating bionematicide effects of *Mentha pulegium* and *Lepidium sativum* on hatching of *Globodera rostochiensis,* 133-138''. Aspects of Applied Biology, 126: Fifth International Symposium of Biofumigation (9-12 September, 2014, Harper Adams University, Shropshire, UK) 154 pp.

Zasada, I. A. & H. Ferris, 2004. Nematode suppression with brassicaceous amendments: application based upon glucosinolate profiles. Soil Biology & Biochemistry, 36 (7): 1017-1024.

Zasada, I. A., S. L. F. Meyer & M. J. Morra, 2009. Brassicaceous seed meals as soil amendments to suppress the plant-parasitic nematodes *Pratylenchus penetrans* and *Meloidogyne incognita*. Journal of Nematology, 41 (3): 221-227.