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Original article (Orijinal araştırma)

Reproduction of *Meloidogyne chitwoodi* Golden et al., 1980 (Tylenchida: Meloidogynidae) on different potato cultivars and its effect on plant growth[1]

Meloidogyne chitwoodi Golden et al.,1980 (Tylenchida: Meloidogynidae)' nin farklı patates çeşitleri üzerindeki üremesi ve bunun bitki gelişimine etkisi

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Abstract

The Columbia root-knot nematode, *Meloidogyne chitwoodi* Golden et al., 1980 (Tylenchida: Meloidogynidae), is one of the most damaging nematode parasites of potato. It can cause economic damage in many cultivated plants and infest weeds. In this study, the reproduction of *M. chitwoodi* was assessed in 19 potato cultivars and one candidate cultivar under climate chamber conditions, and the effects of *M. chitwoodi* on plant growth were assessed in a greenhouse in 2014. *Meloidogyne chitwoodi* reproduced well on the potato cultivars tested based on numbers of egg and egg mass, reproduction factor and egg mass index. There were approximately 2-fold differences between some cultivars according to minimum and maximum values of the number of egg masses (205 in Challenger and 423 in Adora) and reproduction factor (28.2 in Marabel and 58.6 in Adora). Some plant growth parameters were significantly different between nematode inoculated and uninoculated plants for each cultivar according to t-test. Additionally, significant percentage decreases for some plant growth parameters were recorded, including plant height (7.6-13.4%), fresh (14.6-24.5%) and dry (14.2-26.7%) weights of shoots, fresh (15.0-25.1%) and dry (16.2-26.2%) root. It was found that all potato cultivars tested were susceptible to *M. chitwoodi*, and the degree of adverse effect on their growth varied between cultivar.

Keywords: Host, *Meloidogyne chitwoodi*, plant growth, potato, resistance

Öz

Kolombiya kök-ur nematodu, *Meloidogyne chitwoodi* Golden et al., 1980 (Tylenchida: Meloidogynidae), patateste zarar yapan en önemli türlerden biridir. Birçok kültür bitkisinde ekonomik kayıplara neden olabilmekte ve yabancı otları enfekte edebilmektedir. Bu çalışmada, *M. chitwoodi*'nin Türkiye'de yaygın olarak yetiştirilen 19 patates çeşidi ve 1 aday çeşit açısından iklim odası şartlarında üreme durumu ve sera şartlarında bitki gelişimine etkisi 2014 yılında belirlenmiştir. *Meloidogyne chitwoodi*, elde edilen yumurta paketi sayısı, yumurta sayısı, üreme katsayısı ve yumurta paketi indeksine göre patates çeşitlerinin tamamında iyi derecede çoğalmıştır. En çok ve en az üreme görülen çeşitler arasında yumurta paketi sayısı (205, Challenger; 423, Adora) ve üreme katsayısı (28.2, Marabel; 58.6, Adora) açısından yaklaşık 2 kat fark olduğu belirlenmiştir. Bazı bitki büyüme parametrelerinde t-testine göre her çeşidin nematod inokule edilmiş ve edilmemiş bitkileri arasında önemli ölçüde farklılık tespit edilmiştir. Ayrıca, bitki boyu (%7.6-13.4), üst aksam yaş (%14.6-24.5) ve kuru (%14.2-26.7) ağırlığı, kök yaş (15.0-25.1) ve kuru (16.2-26.2) ağırlığını içeren bitki büyüme parametrelerinde önemli bir azalış tespit edilmiştir. Çalışmaya dahil edilen tüm patates çeşitlerinin *M. chitwoodi*'ye duyarlı olduğu ve bitki büyümesine olumsuz etkisinin çeşitlere bağlı olarak değiştiği belirlenmiştir.

Anahtar sözcükler: Konukçu, *Meloidogyne chitwoodi*, bitki gelişimi, patates, dayanıklılık

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Introduction

Potato is one of the most important agricultural products all over the world and is one of the major food sources in many countries. Unlike other important food sources; potato is a key food as it produces more dry-matter and calories per unit area, and has well-balanced protein (Hasan et al., 2014). Turkey has highly suitable conditions for the cultivation of potato, and potatoes are produced almost everywhere in Turkey, with the country ranked nineteenth in global production (Çalışkan et al., 2010; FAO, 2016). In the majority of potato-producing areas of the world, plant-parasitic nematodes, especially potato cyst nematodes and root-knot nematodes, are among the most important pests of the potato. Root-knot nematodes, *Meloidogyne* spp. are obligate parasites and responsible for limiting agricultural productivity. Columbia root-knot nematode *Meloidogyne chitwoodi* Golden, O'Bannon, Santo & Finley, 1980 (Tylenchida: Meloidogynidae) was first described from potatoes (*Solanum tuberosum* L.) in the Pacific Northwest (USA) and has been reported in Africa (South Africa, Mozambique), Europe (Belgium, France, Germany, Netherlands, Portugal, Sweden, Turkey), and North and South America (Mexico, Argentina) (Golden et al., 1980; EPPO, 2018a). In Turkey, *M. chitwoodi* was detected for the first time in potato tubers collected from Niğde Province in 2006 (Özarslandan et al., 2009). It has since been reported in Nevşehir, Konya, Kayseri, Aksaray, Balıkesir, Bitlis, Isparta, İzmir, Kütahya and Manisa Provinces (Yıldız et al., 2009; Ulutaş, 2010; Özarslandan et al., 2013; Evlice & Bayram, 2016).

Meloidogyne chitwoodi has a broad host range comprising several plant families (including Solanaceae, Umbelliferae, Gramineae, Leguminosae, Brassicaceae and Cucurbitaceae) and can cause severe damage to many economically important crops, such as potato, carrot, tomato, carrot, maize, wheat and bean (Santo et al., 1980; O'Bannon et al., 1982; Brinkman et al., 1996; den Nijs et al., 2004). In potato, it causes blisters on the tuber surface and brownish spots in the tuber tissue, as well as infecting the roots, and tubers with these internal and external symptoms are unmarketable for fresh consumption or processing. The economic loss caused by *M. chitwoodi* can reach $9900/ha (Ingham et al., 2007). The economic damage threshold for quality loss of potatoes has been established at 1 J2 (second-stage juvenile)/250 ml of soil in the USA and 10 J2s/100 ml of soil in the Netherlands (Santo et al., 1981; Norshie et al., 2011). However, due to the rapid multiplication of the *M. chitwoodi*, the environmental factors such as temperature, growing season, soil structure are much more important determinants of damage. Spread and damage were observed in the areas with sandy soil with over 1500 degree-days (>5°C) (Griffin, 1985; Pinkerton et al., 1991). *Meloidogyne chitwoodi* is generally regarded as a quality pest (Suffert & Giltrap, 2012), but it also reduced plant development and tuber yield (Santo & O'Bannon, 1981; Pinkerton et al., 1986; Scholte, 1990; Hafez & Sundararaj, 2009). This paper reports reproduction of *M. chitwoodi* on some potato cultivars and its effect on their growth.

Material and Methods

Nematode inoculum

A population of *M. chitwoodi* (NEV-10) was used in this study. Pure stock culture of NEV-10 (Suvermez Kasabası/Nevşehir, 38°21'48.60" N, 34°40'16.20" E) was identified by morphological and molecular methods (Evlice & Bayram, 2016). Nematode cultures were maintained on tomato plants (*Solanum lycopersicum* cv. Tueza) in a climate chamber. Four leaf stage tomato seedlings, established in pots (760 ml, 10x10x11 cm), were inoculated with 10-15 egg masses and allowed to multiply for 8 weeks (Mistanoğlu et al., 2016). Egg masses were collected from infected roots and J2s were obtained using a Petri dish method at 23ºC. J2s that hatched in the first 24 h were discarded, and thereafter J2s were collected and stored at 4ºC. J2s were used within 72 h for inoculation (Nyczepir et al., 1999).

Plant material

Nineteen potato cultivars, the most commonly cultivated in Turkey and one candidate cultivar from Turkey were used in this study (Table 1). Except the candidate cultivar, only certified potato tubers were tested. Of the tested cultivars, eight were grown from mini tubers. For the others tuber were cut into 25-28 mm pieces. Tubers were sprouted to about 1 cm long before planting, with excess sprouts removed to obtain tubers with single sprout for planting.

Reproduction of *Meloidogyne chitwoodi* on potato cultivars

All experiments were conducted at Plant Protection Central Research Institute (Ankara, Turkey) in 2014. The experiment was conducted in a climate chamber at 23±2ºC with a 14:8 h L:D photoperiod (3000 lux). The plants were established in pots (550 ml, 9x9x10 cm) filled with autoclaved (Smith & Onions, 1994) soil mixture (85% silver sand, 15% soil). Osmocote® (Scotts, Marysville, OH, USA) (18-6-12), a slow release fertilizer, was applied at a rate of 1 g/kg soil mixture. Five pots for each cultivar were inoculated with 750 J2 (the initial population density, Pi) at planting. The inoculum was delivered into 3-4 cm deep holes and covered with soil. Tomato plants (Tueza F1) served as a susceptible control. The pots were arranged in a completely randomized design. Plants were watered and fertilized regularly. Sixty days after inoculation, plants were removed from the pots, the root systems were gently washed with tap water and then soaked in a Phloxine B solution (0.15-0.20 g/L; Sigma-Aldrich, St. Louis, MO, USA) to stain nematode egg masses. Gall and egg masses per root system were counted and ranked on a scale of 0 to 10, where 0 = no galls or no egg masses, 1 = 1-2, 2 = 3-10, 3 = 11-30, 4 = 31-100, 5= more than 100 galls or egg masses per root system, and the cultivars assigned according to egg mass index (EI) (Hartman & Sasser, 1985). Eggs were extracted from roots (Hartman & Sasser, 1985), the final population (Pf) and reproduction factor (Rf = Pf/Pi) was determined. Cultivars were classified as non-host (immune) (EI = 0 and Rf = 0), poor host (resistant) (EI = 1-3 and Rf < 1) and a suitable host (susceptible) (EI = 4-5 and Rf > 1) (Oostenbrink, 1966).

Effect of *Meloidogyne chitwoodi* on plant growth

An experiment was conducted in a greenhouse and uninoculated plants were included for comparing some vegetative parameters. The experiment was designed as previously indicated. The pots were arranged randomly on a bench in greenhouse (24.4±4.7ºC) with a 16:8 h L:D photoperiod. Plants were watered and fertilized regularly. The experiment was terminated 60 d after inoculation. The roots were stained and the egg masses counted. Plant shoots and roots were dried at 70ºC in an oven for 48 h and dry weights determined (Mohammad et al., 2007). Plant growth was assessed as plant height (cm), and fresh and dry weights (g) of shoots and roots.

Statistical analysis

The mean numbers of egg masses and reproduction factor were square root transformed. Variance analysis was performed with transformed data and the differences between treatments were analyzed by means of Duncan's multiple range test ($P < 0.05$). Plant growth parameters as plant height (cm), and fresh and dry weights (g) of shoots and roots were analyzed by paired t-test. All statistical analyses were performed using SPSS 20 software (IBM Corp., Armonk, NY, USA).

Results

Reproduction of *Meloidogyne chitwoodi* on potato cultivars

Egg masses of *M. chitwoodi* were observed on all plants tested (Table 1). The number of egg masses on each root system ranged from 205 to 423 and showed significant variation ($F = 3.24$ $P < 0.05$) between the cultivars. Challenger (205), Van Gogh (216), Marabel (229), Granola (249) and Orchestra (251.00) had the lowest mean number of egg masses. However, the highest number of egg masses were in Adora (423), Hermes (374), Lady Rosetta (358), 614002 (353) and Melody (324). *Meloidogyne chitwoodi* reproduced on all the cultivars with significant differences ($F = 3.15$, $P < 0.05$) between the cultivars. The highest Rf of *M. chitwoodi* was in Adora (58.6) followed by 614002 (58.0), Hermes (56.2), Lady Rosetta (56.2) and Agria (44.8). Whereas, the lowest Rf values were in Marabel (28.2), Challenger (29.0), Orchestra (30.0), Pomquen (31.0) and Van Gogh (32.8). Therefore, all the potato cultivars were classified as susceptible, having a ranking of 5 and $R > 1$. Few or no galls were detected on the potato roots, but were observed on the tomato roots (Figure 1). However, these galls are not considered to be as large a problem as those induced by other *Meloidogyne* species, such as *M. incognita* and *M. javanica*. Santo et al. (1980) and Golden et al. (1980) also reported that *M. chitwoodi* causes little or no galling on roots of potato and tomato cv. Rutgers.

Table 1. Number of egg masses, reproduction factor (Rf: Pf/Pi) and egg mass index of *Meloidogyne chitwoodi* on different potato cultivars 60 d after inoculation with 750 second-stage juveniles

Cultivar	Number of egg masses[1]		Rf[1]		Egg-mass index
Adora	423±37	a[2]	58.6±5.8	ab	5
Agria	273±25	abcd	44.8±5.2	abc	5
Alegria	285±31	abcd	39.4±4.4	abc	5
Borwina	281±18	abcd	37.0±2.1	abc	5
Challenger	205±9	d	29.0±6.1	bc	5
Granola	249±21	abcd	41.2±3.4	abc	5
Hermes	374±34	abc	56.2±8.2	abc	5
İnnovator	291±16	abcd	37.4±2.3	abc	5
Jearla	312±18	abcd	42.8±6.5	abc	5
Lady Olimpia	263±40	abcd	44.6±7.4	abc	5
Lady Rosetta	358±30	abcd	56.2±5.2	abc	5
Marabel	229±27	bcd	28.2±3.1	c	5
Melody	324±38	abcd	38.2±7.3	abc	5
Orchestra	251±33	abcd	30.0±1.3	bc	5
Pomqueen	310±42	abcd	31.0±6.8	bc	5
Russet	263±23	abcd	42.8±6.8	abc	5
Spunta	314±64	abcd	37.2±7.2	abc	5
Toscana	260±26	abcd	36.8±5.5	abc	5
Van Gogh	216±26	cd	32.8±3.1	abc	5
614002	353 ±10	abcd	58.0±4.3	abc	5
Tomato	391±48	ab	64.2±11.7	a	5

[1] Data are means±SE;
[2] Different letters following means in the same column indicate statistical significance from each other (ANOVA $P < 0.05$, Duncan's multiple range test).

Figure 1. Symptoms caused by *Meloidogyne chitwoodi* on roots of potato plant stained with Phloxine B.

Effect of *Meloidogyne chitwoodi* on plant growth

The mean plant growth parameters with and with nematode inoculation are shown in Table 2 along with the number of egg mass on the inoculated plants. Egg masses were detected on all cultivars, with mean number differing significantly ($F = 2.09$, $P < 0.05$) between cultivars. The highest number of egg masses were on Adora (389), Lady Rosetta (363), Hermes (360), Jearla (359) and Alegria (337), while Toscana (233), Agria (241), Challenger (243), Lady Olympia (254) and Marabel (268) had the lowest number.

Table 2. Effect of *Meloidogyne chitwoodi* on the plant growth of different potato cultivars 60 days after inoculation with 750 second-stage juveniles[1]

Cultivar	Nematode[2]	Plant height (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)	Egg mass number**
Adora	+	94±2.4*	25.5±1.3*	5.1±0.1*	13.8±0.9*	1.7±0.2	389±37 a
	-	106±2.3	34.2±1.8	5.9±0.2	18.1±0.9	2.3±0.2	
Agria	+	106±1.4	19.3±0.7*	4.5±0.1	15.1±0.9*	1.7±0.1	241±15 d
	-	114±5.7	22.9±0.8	4.8±0.1	18.1±1.8	2.1±0.1	
Alegria	+	86±4.5	26.6±1.3*	5.2±0.1	12.9±0.8*	1.5±0.2	337±60 abcd
	-	93±3.6	31.6±1.5	5.7±0.1	15.9±1.2	1.8±0.2	
Borwina	+	90±3.8	18.7±0.6*	4.4±0.1*	17.3±0.7*	1.7±0.2	301±31 abcd
	-	102±4.8	23.5±1.2	4.9±0.1	20.6±0.7	2.1±0.3	
Challenger	+	93±4.0	27.9±1.1*	5.3±0.1*	18.2±1.0*	2.0±0.3	243±42 d
	-	101±3.5	32.9±1.2	5.8±0.1	22.1±1.4	2.7±0.3	
Granola	+	86±1.8	21.6±1.1*	4.7±0.1*	14.5±0.9*	1.6±0.1	299±36 abcd
	-	96±5.8	26.8±1.1	5.2±0.1	19.2±1.2	1.9±0.2	
Hermes	+	92±2.9*	19.9±1.3*	4.5±0.1	13.8±0.7*	1.8±0.1	360±20 abc
	-	107±2.8	24.5±0.9	5.0±0.1	17.3±1.7	2.4±0.2	
İnnovator	+	89±.3.2	23.5±1.6*	4.9±0.2	17.6±1.6*	1.7±0.2	279±35 abcd
	-	98±4.7	27.9±2.9	5.3±0.3	21.1±1.2	2.1±0.2	
Jearla	+	108±2.9	24.9±0.9*	5.0±0.1	15.2±1.5*	1.9±0.2	359±32 abc
	-	117±5.7	29.2±1.3	5.5±0.1	18.3±1.5	2.4±0.2	
Lady Olympia	+	102±3.8	23.2±1.4*	4.9±0.1*	16.2±0.8*	1.6±0.2	254±21 cd
	-	117±5.5	27.1±2.1	5.2±0.2	19.6±0.8	2.1±0.2	
Lady Rosetta	+	73±3.0	22.8±1.5*	4.8±0.2*	17.7±1.0*	2.1±0.2	363±30 abc
	-	82±2.7	29.4±2.2	5.5±0.2	21.6±1.2	2.6±0.4	
Marabel	+	93±3.5*	21.6±1.7*	4.7±0.2*	15.6±0.7*	1.8±0.1	268±28 cd
	-	106±2.7	25.9±1.8	5.1±0.2	18.7±1.0	2.3±0.2	

Table 2. (Continued)

Cultivar	Nematode[2]	Plant height (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)	Egg mass number**
Melody	+	94±3.3	23.3±1.9*	4.9±0.2	14.9±1.0*	1.9±0.3	279±33 abcd
	-	103±4.7	28.5±1.5	5.4±0.1	18.6±0.9	2.3±0.3	
Orchestra	+	109±1.9*	25.4±1.7*	5.1±0.2*	15.7±1.2*	1.6±0.1	277±43 bcd
	-	126±3.9	29.1±0.8	5.4±0.1	20.9±1.1	2.2±0.3	
Pomqueen	+	108±2.7*	22.8±1.4*	4.8±0.2*	15.4±0.7*	1.7±0.2	289±12 abcd
	-	120±1.9	27.5±1.3	5.3±0.1	18.7±1.1	2.1±0.3	
Russet	+	89±3.0	22.5±0.9*	4.8±0.1	17.2±0.9*	1.7±0.2	314±22 abcd
	-	100±4.7	26.3±1.8	5.2±0.2	20.3±1.1	2.1±0.2	
Spunta	+	99±4.6*	20.7±0.9*	4.6±0.1*	17.5±1.0*	1.8±0.2	293±21 abcd
	-	114±3.1	25.9±1.0	5.1±0.1	20.8±0.7	2.2±0.2	
Toscana	+	75±1.8*	17.5±0.9*	4.2±0.1*	14.3±0.8*	1.6±0.1	233±11 d
	-	84±2.9	21.6±0.9	4.7±0.1	17.5±0.9	1.9±0.1	
Van Gogh	+	90±.3.6*	23.8±0.8*	4.9±0.1*	17.6±0.8*	1.8±0.1	299±32 abcd
	-	100±1.2	28.9±1.1	5.4±0.1	20.8±1.1	2.2±0.2	
614002	+	73±2.9	19.0±1.3*	4.2±0.1	14.4±0.9*	1.7±0.2	297±36 abcd
	-	81±2.1	23.4±1.0	4.6±0.1	17.5±0.8	2.2±0.2	
Tomato	+	47±3.1	25.1±1.7*	5.1±0.2*	13.8±0.5*	2.1±0.2	380±18 ab
	-	52±3.6	29.1±0.7	5.4±0.1	17.9±1.7	2.8±0.2	

[1] Data is means±SE, n = 5;
[2] +: Nematode inoculated; -: Nematode uninoculated;
* Values between nematode inoculated and uninoculated plants of each cultivar are significantly different according to t-test ($P < 0.05$);
** Values indicated by the same letter are not significantly different according to Duncan's multiple range test at $P < 0.05$.

The growth parameters varied between cultivars, but there was no significant difference for some parameters between some cultivars. All cultivars showed significant decrease in shoot and root fresh weight, but no significant difference was found fin root dry weight. All parameters except dry root weight decreased significantly in Adora, Marabel, Orchestra, Pomqueen, Spunta, Toscana and Van Gogh. However, plant height, fresh and dry weights of shoots and roots were reduced by *M. chitwoodi* relative to uninoculated plants. For inoculated and uninoculated plants, the lowest plant heights (cm) were in Lady Rosetta (73 and 82, respectively) and 614002 (73 and 81), and the highest in Orchestra (109 and 126) and Pomqueen (108 and 120). The lowest shoot fresh weight was in Toscana (17.5, 21.6) and Borwina (18.7 and 23.5), the highest in Challenger (27.9 and 32.9) and Alegria (26.6, 31.6). The lowest and highest shoot dry weights were in 614002 (4.2 and 4.6) and Challenger (5.3 and 5.8), respectively. The lowest root fresh and dry weights were obtained in Alegria (12.9 and 15.9, and 1.5 and 1.8) while the highest root fresh and dry weights were in Challenger (18.2 and 22.1, and 2.0 and 2.7, respectively).

The percent effects on plant growth parameters due to the nematode inoculation are shown in Table 3. Plant height, fresh and dry weights of shoots and roots of the cultivars were reduced by inoculation with *M. chitwoodi* relative to uninoculated plants, but there were no significant differences between the cultivars ($P > 0.05$). The greatest decrease in plant height was in Hermes (13.4%) followed by Spunta (13.3%) and Orchestra (12.3%), while the least effects were in Alegria (7.6%), Agria (7.8%) and Melody (7.9%). The greatest effect on fresh and dry weight of shoots was in Adora (24.5 and 26.7%, respectively), followed by Lady Rosetta (21.8%) and Borwina (20.0%) for shoot fresh weight and Marabel (22.4%) and Hermes (21.98%) for shoot dry weight. The least effect on shoot fresh weight were in Orchestra (14.6%), Russet (14.6%) and Innovator (14.8%). For shoot dry weight, the least effect was in Jearla (14.2%), Spunta (14.3%) and Lady Olympia (15.6%). The greatest effects on root fresh and dry weights were in Orchestra (25.1%), Granola (24.4%), Adora (23.6%) and Challenger (26.2%), and in Adora (24.1%) and Innovator (23.8%), respectively. Whereas, the least effects were detected in Van Gogh (15.0%), Spunta (15.6%), Marabel (15.6%) and Pomqueen (16.2%), and Jearla (16.6%) and Alegria (17.2%), respectively.

Table 3. Percentage reduction in the plant growth of different potato cultivars caused by *Meloidogyne chitwoodi* 60 days after inoculation with 750 second-stage juveniles[1]

Cultivar	Plant height (%)	Shoot fresh weight (%)	Shoot dry weight (%)	Root fresh weight (%)	Root dry weight (%)
Adora	11.9±3.1	24.5±5.3	26.7±6.2	23.6±3.6	24.1±10.5
Agria	7.8±4.1	15.6±1.4	20.8±6.3	15.6±5.2	20.5±8.0
Alegria	7.6±1.9	15.7±3.2	17.2±5.9	17.6±7.1	17.2±6.5
Borwina	11.5±2.2	20.0±2.5	20.8±3.4	16.0±4.1	21.1±7.7
Challenger	8.5±1.8	15.4±1.8	16.8±2.8	17.4±4.3	26.2±11.5
Granola	9.4±3.5	19.1±2.8	21.1±5.1	24.4±6.9	19.6±3.7
Hermes	13.4±4.1	18.4±4.6	21.9±3.8	18.8±5.4	22.4±8.1
İnnovator	9.0±2.2	14.8±3.6	20.8±4.7	16.9±7.4	23.8±7.8
Jearla	9.7±3.6	15.8±4.6	14.2±5.1	17.3±6.4	16.6±10.0
Lady Olympia	12.1±5.5	15.7±5.9	15.6±5.6	17.3±4.7	23.7±4.3
Lady Rosetta	10.4±4.6	21.8±4.3	18.5±7.8	19.7±5.7	23.6±8.6
Marabel	11.9±1.8	17.9±4.9	22.4±8.3	15.6±5.1	21.9±6.2
Melody	7.9±2.3	18.5±3.5	19.9±5.4	18.2±5.6	19.1±6.7
Orchestra	12.3±4.0	14.6±5.3	17.5±7.7	25.1±4.0	22.9±11.1
Pomqueen	10.0±2.9	17.1±3.2	19.9±7.5	16.7±3.2	16.2±5.7
Russet	9.7±3.9	14.6±4.9	17.3±8.1	15.7±7.2	20.7±8.3
Spunta	13.3±3.4	19.5±5.8	14.3±5.5	15.6±4.9	22.4±9.8
Toscana	10.2±1.9	19.1±2.3	18.5±3.1	18.1±4.2	19.3±6.7
Van Gogh	9.8±3.8	17.1±3.8	19.6±6.9	15.0±2.8	18.3±5.4
614002*	8.9±3.3	18.9±2.9	21.1±11.4	17.3±6.3	22.7±5.7
Tomato	9.4±4.5	13.8±5.5	18.3±2.6	20.5±7.2	23.1±2.9

[1] Values are means±SE of five replicates. Percentage reduction in plant growth of cultivars do not differ significantly according to Duncan's multiple range test at $P < 0.05$;
* Candidate cultivar.

Discussion

Meloidogyne chitwoodi, a sedentary endoparasite nematode, causes damage to roots, stolons and tubers of potato. Tuber infection can result in both external symptoms, galling to the surface, and internal symptoms, brown spots surrounding adult females that are visible when the tuber is peeled. Infested tubers are not suitable for the fresh market or processing when these symptoms reach 5% or more (EPPO, 2018b). Potato is known as a good host for *M. chitwoodi* and it is generally considered quality pest for potato (Norshie et al., 2011). In addition to the quality damage caused by *M. chitwoodi*, the overall tuber yield can also be reduced (EPPO, 2018b). The results obtained from this experiment show that reproduction of *M. chitwoodi* and effect of *M. chitwoodi* infection on plant growth parameters as plant height, fresh and dry weights of shoots and roots vary between different cultivars. *Meloidogyne* species (*M. incognita*, *M. javanica*, *M. arenaria* and *M. mayaguensis*) having high reproduction potential in potato, but differences between the cultivars have been reported (Al-Hazmi et al., 1995; Ateka et al., 2001; Vovlas et al., 2005; Silva et al., 2010; Ibrahim et al., 2014).

Santo & O'Bannon (1981) found that *M. chitwoodi* and *M. hapla* reduced root growth and tuber yield of potato. *Meloidogyne chitwoodi* reduced tuber yield and yield loss reached 25% in the greenhouse and open field studies (Hafez & Sundararaj, 2002, 2006a, b, 2009). It has been found that the yield loss due to *M. chitwoodi* can be reduced by 17-40% as a result of the nematicide applications (Pinkerton et al., 1986; Scholte, 1990). *Meloidogyne chitwoodi* reduces both fresh and dry shoot and root weights of tomato up to 37 and 45%, respectively (Santo & O'Bannon, 1982; Hafez & Sundararaj, 1999). The damage caused by *M. chitwoodi* to potato tubers has been shown to vary between cultivars. Some potato cultivars have a lower tuber damage than others, for example Agria is reported to be much more tolerant than Hansa (Suffert & Giltrap, 2012). Under field conditions, it has been reported that the symptoms caused by *M. chitwoodi* in the tubers varied from 3 to 34%, and the maximum population density was 2778 and 4167 J2/100 cm^3 soil in the early and late cultivars, respectively (Van Riel, 1993, 1994). Separate resistance genes for root reproduction and tuber infection have been found against *M. chitwoodi* in potato (Brown et al., 1996, 2009). Additionally, some promising results have been reported for resistant commercial potato cultivar using these genes (Brown et al., 1991, 2004, 2006, 2009; Norshie et al. 2011; Dinh et al., 2014). Studies have also shown plant growth reduction due to *M. chitwoodi*, depending on temperature and population density, in host plants such as alfalfa, wheat, barley, carrot and some other legumes (Nyczepir et al., 1984; Griffin et al., 1986; Griffin, 1992, 1993; Griffin & Rumbaugh, 1996; Griffin & Jensen, 1997; Molendijk & Brommer, 1998).

Some studies reported that no yield loss was caused by *M. chitwoodi* in potatoes, but this is considered to be due to the specific environmental conditions, such as total grade-days, initial population and soil type (Mojtahedi et al., 1993; Umesh & Ferris 1994; Hafez & Sundararaj, 2003). However, total potato yield reduction due to *M. chitwoodi* in two out of five years was reported in a field experiment, therefore, the damage varies depending on the region (Griffin, 1985; Pinkerton et al., 1991). The damage threshold for *M. chitwoodi* was 1 J2/250 ml soil in the USA and 10 J2/100 ml soil in the Netherlands. Therefore, potatoes can lose market value when grown in the areas which have higher juvenile numbers than these thresholds (Santo et al., 1981; Norshie et al., 2011). However, for nematode damage, the environmental conditions can be more important than the initial populations of *M. chitwoodi*. Spread and damage of *M. chitwoodi* has been observed in the areas with coarse soil texture and an annual degree-day (>5°C) of at least 1500 (Griffin, 1985; Pinkerton et al., 1991). In infested areas, the level of damage was affected by temperature, the type of plant grown (sensitive, tolerant or durable), the duration and period of the production, soil structure, and rainfall and watering conditions.

In summary, this study showed that *M. chitwoodi* reproduced well in all potato cultivars tested and caused reduction in their growth. However, there was significantly difference between cultivars in nematode reproduction and effects on plant growth. Damage to tubers may be reduced by choice of less susceptible cultivars. Thus, correct diagnosis and estimation of soil population densities of *M. chitwoodi* should be performed before planting potato to facilitate effective integrated management. Furthermore, integrated management programs for *M. chitwoodi* should be established, and farmers should be informed about its importance and potential to cause damage.

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References

Al-Hazmi, A. S., A. A. M. İbrahim & A. T. Abdul-Razig, 1995. Host suitability of some potato cultivars to *Meloidogyne javanica*. Journal of King Saud University Agricultural Sciences: 7 (1): 103-107.

Ateka, E. M., A. W. Mwang'Ombe & J. W. Kimenju, 2001. Studies on the interaction between *Ralstonia solanacearum* (Smith) and *Meloidogyne* spp. in potato. African Crop Science Journal, 9 (3): 527-535.

Brinkman, H., J. M. Goossens & H. R. Van Riel, 1996. Comparative host suitability of selected crop plants to *Meloidogyne chitwoodi* Golden et al. 1980 and *M. fallax* Karssen et al. 1996. Anzeiger für Schädlingskunde Pflanzenschutz Umweltschutz, 96: 127-129.

Brown, C. R., H. Mojtahedi & G. S. Santo, 1991. Resistance to Columbia root-knot nematode in *Solanum* ssp. and in hybrids of *S. hougasii* with tetraploid cultivated potato. American Journal of Potato Research, 68 (7): 445-452.

Brown, C. R., C. P. Yang, H. Mojtahedi, G. S. Santo & R. Masuelli, 1996. RFLP analysis of resistance to Columbia root-knot nematode derived from *Solanum bulbocastanum* in a BC 2 population. Theoretical and Applied Genetics, 92 (5): 572-576.

Brown, C. R., H. Mojtahedi & J. Bamburg, 2004. Evaluation of *Solanum fendleri* as a source of resistance to *Meloidogyne chitwoodi*. American Journal of Potato Research, 81: 415-419.

Brown, C. R., H. Mojtahedi, S. James, R. G. Novy & S. Love, 2006. Development and evaluation of potato breeding lines with introgressed resistance to Columbia root-knot nematode (*Meloidogyne chitwoodi*). American Journal of Potato Research, 83: 1-8.

Brown, C. R., H. Mojtahedi, L. H. Zhang & E. Riga, 2009. Independent resistant reactions expressed in root and tuber of potato breeding lines with introgressed resistance to *Meloidogyne chitwoodi*. Phytopathology, 99 (9): 1085-1089.

Çalışkan, M. E., H. Onaran & H. Arıoğlu, 2010. Overview of the Turkish potato sector: challenges, achievements and expectations. Potato Research, 53 (4): 255-266.

den Nijs, L. J. M. F., H. Brinkman & A. T. C. Van der Sommen, 2004. A Dutch contribution to knowledge on phytosanitary risk and host status of various crops for *Meloidogyne chitwoodi* Golden *et al.*, 1980 and *M. fallax* Karssen, 1996: an overview. Nematology, 6 (3): 303-312.

Dinh, P. T. Y., C. R. Brown & A. A. Elling, 2014. RNA interference of effector gene Mc16D10L confers resistance against *Meloidogyne chitwoodi* in *Arabidopsis* and potato. Phytopathology, 104 (10): 1098-1106.

EPPO, 2018a. EPPO Global Database. *Meloidogyne chitwoodi* distribution. (Web page: https://gd.eppo.int/taxon/MELGCH/distribution) (Date accessed: 30 August 2018).

EPPO, 2018b. EPPO Data Sheets on Quarantine Pests *Meloidogyne chitwoodi*. (Web page: https://gd.eppo.int/download/doc/167_datasheet_MELGCH.pdf) (Date accessed: 6 October. 2018).

Evlice, E. & Ş. Bayram, 2016. Identification of root-knot nematode species (*Meloidogyne* spp.) (Nemata: Meloidogynidae) in the potato fields of Central Anatolia (Turkey) using molecular and morphological methods. Turkish Bulletin of Entomology, 6 (4): 339-347.

FAO, 2016. FAOSTAT-Agriculture. (Web page: http://www.fao.org/faostat/en/#data/QC) (Date accessed: 20 March 2018).

Golden, A. M., J. H. Obannon, G. S. Santo & A. M. Finley, 1980. Description and some observations of *Meloidogyne chitwoodi* n. sp. (Meloidogynidae), a root-knot nematode on potato in the Pacific Northwest. Journal of Nematology, 12 (4), 319-327.

Griffin, G. D., 1985. Host-parasite relationship of *Meloidogyne chitwoodi* on potato. Journal of Nematology, 17 (4): 395-399.

Griffin, G. D., 1992. Comparative effects of two populations of *Meloidogyne chitwoodi* on *Triticum aestivum* and *Hordeum vulgare*. Nematropica, 22: 65-74.

Griffin, G. D., 1993. Influence of temperature on the virulence of two races of *Meloidogyne chitwoodi* on wheat and barley. Journal of Nematology, 25: 454-460.

Griffin, G. D. & M. D. Rumbaugh, 1996. Host suitability of twelve Leguminosae species to populations of *Meloidogyne hapla* and *M. chitwoodi*. Journal of Nematology, 28: 400-405.

Griffin, G. D. & K. B. Jensen, 1997. Importance of temperature in the pathology of *Meloidogyne hapla* and *M. chitwoodi* on legumes. Journal of Nematology, 29: 112-116.

Griffin, G. D., R. N. Inserra, N. Vovlas & D. V. Sisson, 1986. Differential reaction of alfalfa cultivars to *Meloidogyne hapla* and *M. chitwoodi* populations. Journal of Nematology, 18: 347-352.

Hafez, S. L. & P. Sundararaj, 1999. Efficacy of seed crop meals for the management of Columbia root-knot nematode *Meloidogyne chitwoodi* on tomato under greenhouse conditions. Nematropica, 29 (2): 171-177.

Hafez, S. L. & P. Sundararaj, 2002. Efficacy of chemical nematicides for the management of *Meloidogyne chitwoodi* on potato. International Journal of Nematology, 12: 76-78.

Hafez, S. L. & P. Sundararaj, 2003. Efficacy of fosthiazate for the control of *Meloidogyne chitwoodi* on potato. International Journal of Nematology, 13: 201-203.

Hafez, S. L. & P. Sundararaj, 2006a. Evaluation of fumigant and non-fumigant nematicides for the control of *Meloidogyne chitwoodi* on potato. Nematologia Mediterranea, 34: 147-149.

Hafez, S. L. & P. Sundararaj, 2006b. Efficacy of fosthiazate for the control of *Paratrichodorus* spp. and *Meloidogyne chitwoodi* on potato. International Journal of Nematology, 16: 157-160.

Hafez, S. L. & P. Sundararaj, 2009. Chemical management practices of *Meloidogyne chitwoodi* in a potato field in USA. International Journal of Nematology, 19: 203-207.

Hartman, K. M. & J. N. Sasser, 1985. "Identification of *Meloidogyne* Species on the Basis of Differential Host Test and Perineal-Pattern Morphology, 69-77". In: An Advanced Treatise on *Meloidogyne* Volume II: Methodology (Eds. K. R. Barker, C. C. Carter & J. N. Sasser). North Carolina State University Graphics, Raleigh, NC, USA, 223 pp.

Hasan, H. H., S. Simon & A. A. Lal, 2014. Effect of selected botanical extracts against *Meloidogyne incognita* (Kofoid and White) Chitwood on potato (*Solanum tuberosum* L.). International Journal of Agricultural Science and Research, 4 (3): 101-108.

Ibrahim, I. K. A., A. A. Mokbel & S. E. Hammad, 2014. Host suitability of some Solanaceous plant cultivars to the root-knot nematodes, *Meloidogyne* spp. Global Advanced Research Journal of Agricultural Science. 3 (5): 136-140.

Ingham, R. E., P. B. Hamm, M. Baune, N. L. David & N. M. Wade, 2007. Control of *Meloidogyne chitwoodi* in potato with shank-injected metam sodium and other nematicides. Journal of nematology, 39 (2): 161.

Mistanoğlu, İ., T. Özalp & Z. Devran, 2016. Response of tomato seedlings with different number of true leaves to *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949. The Turkish Journal of Entomology, 40 (4): 377-383.

Mohammad, A. B., Z. Eskandar, S. Saeid, J. Mohammad & M. Fariba, 2007. Evaluation of sulfosulfuron for broad leaved and grass weed control in wheat (*Triticum aestivum* L.) in Iran. Crop Protection, 26 (9): 1385-1389.

Mojtahedi, H., G. S. Santo, J. H. Wilson & A. N. Hang, 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. Plant Disease, 77: 42-46.

Molendijk, L. P. G. & E. Brommer, 1998. Postponement of sowing reduces quality damage in carrots (*Daucus carota*) caused by *Meloidogyne fallax*. Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen Universiteit Gent, 63: 655-658.

Norshie, P. M., T. H. Been & C. H. Schomaker, 2011. Estimation of partial resistance in potato genotypes against *Meloidogyne chitwoodi.* Nematology, 13 (4): 477-489.

Nyczepir, A. P., R. N. Inserra, J. H. O'Bannon & G. S. Santo, 1984. Influence of *Meloidogyne chitwoodi* and *Meloidogyne hapla* on wheat growth. Journal of Nematology, 16: 162-165.

Nyczepir, A. P., T. G. Beckman & G. L. Reighard, 1999. Reproduction and development of *Meloidogyne incognita* and *M. javanica* on Guardian peach rootstock. Journal of nematology, 31 (3): 334.

O'Bannon, J. H., G. S. Santo & A. P. Nyczepir, 1982. Host range of the Columbia root-knot nematode. Plant Disease, 66 (11): 1045-1048.

Oostenbrink, M., 1966. Major characteristics of the relation between nematodes and plant. Mededelingen Landbouwhogeschool Wageningen, 66: 1-46.

Özarslandan, A., Z. Devran, N. Mutlu & İ. H. Elekçioğlu, 2009. First report of Columbia root-knot nematode (*Meloidogyne chitwoodi*) in potato in Turkey. Plant Disease, 93: 316.

Özarslandan, A., M. İmren, A. Öcal & İ. H. Elekçioğlu, 2013. Bitlis ili patates üretim alanlarında kök-ur nematodu (*Meloidogyne chitwoodi* Golden, O'Bannon, Santo et Finley, 1980)'nun saptanması. Türkiye Entomoloji Dergisi, 37 (3): 389-395.

Pinkerton, J. N., G. S. Santo, R. P. Ponti & J. H. Wilson, 1986. Control of *Meloidogyne chtitwoodi* in commercially grown Russet Burbank potatoes. Plant Disease*,* 70: 860-863.

Pinkerton, J. N., G. S. Santo & H. Mojtahedi, 1991. Population dynamics of *Meloidogyne chitwoodi* on Russet Burbank potatoes in relation to degree-day accumulation. Journal of Nematology, 23: 283-290.

Santo, G. S., J. H. O'Bannon, A. M. Finley & A. M. Golden, 1980. Occurrence and host range of a new root-knot nematode (*Meloidogyne chitwoodi*) in the Pacific Northwest. Plant Disease, 64 (10): 951-952.

Santo, G. S., J. H. O'Bannon, A. P. Nyczepir & R. P. Ponti, 1981. "Ecology and control of root-knot nematodes on potato, 135-139". Proceedings of the 20th Annual Washington Potato Conference (3-5 February, Moses Lake, Washington, USA). Washington State Potato Commission, Moses Lake, WA, USA.

Santo, G. S. & J. H. O'Bannon, 1981. Effect of soil temperature on the pathogenicity and reproduction of *Meloidogyne chitwoodi* and *M. hapla* on Russet Burbank potato. Journal of Nematology, 13 (4): 483-486.

Santo, G. S. & J. H. O'Bannon, 1982. Reaction of tomato cultivars to *Meloidogyne chitwoodi* and *Meloidogyne hapla*. Plant Disease, 66 (5): 406-407.

Scholte, K., 1990. Causes of differences in growth-pattern, yield and quality of potatoes (*Solanum tuberosum* L.) in short rotations on sandy soil as affected by crop rotation, cultivar and application of granular nematicides. Potato Research, 33: 181-190.

Silva, A. R., J. M. Santos, P. C. R. Hayashi & E. Hayashi, 2010. Reaction of potato clones and cultivars evaluated in greenhouse to *Meloidogyne incognita*, *M. javanica* and *M. mayaguensis* and *in vitro* to *M. javanica*. Nematologia Brasileira, 34 (1): 48-55.

Smith, D. & A. H. S. Onions, 1994. The Preservation and Maintenance of Living Fungi. CAB International, Wallingford, England, UK,112 pp.

Suffert, M. & N. Giltrap, 2012. EPPO Workshop on *Meloidogyne chitwoodi* and *Meloidogyne fallax* (2011-03-08): Importance for potato production and experience of management in EPPO countries. EPPO Bulletin, 42: 117-121.

Ulutaş, E., 2010. Ege Bölgesi Patates Üretim Alanlarında Bulunan Önemli Bitki Paraziti Nematodların Belirlenmesi ve Bitki Gelişimine Etkileri. Ege Üniversitesi Fen Bilimleri Enstitüsü, (Basılmamış) Doktora Tezi, 92+XVIII s. Bornova, İzmir.

Umesh, K. C. & H. Ferris, 1994. Influence of temperature and host plant on the interaction between *Pratylenchus neglectus* and *Meloidogyne chitwoodi*. Journal of Nematology, 26 (1): 65-71.

Van Riel, H. R., 1993. Comparison of potato cultivars in relation to their level of external symptoms in tubers caused by *Meloidogyne chitwoodi*. Mededelingen van de Faculteit Landbouw, Universiteit Gent, 58/2b: 737-742.

Van Riel, H. R., 1994. Populations dynamics of *Meloiogyne chitwoodi* on various potato cultivars. Mededelingen van de Faculteit Landbouw, Universiteit Gent, 59/2b: 791-800.

Vovlas, N., D. Mifsud, B. B. Landa & P. Castillo, 2005. Pathogenicity of the root knot nematode *Meloidogyne javanica* on potato. Plant Pathology, 54: 657-664.

Yıldız, V., Ç. Güneş, N. Bulun & U. Gözel, 2009. "Ödemiş (İzmir) ilçesi patates üretim alanlarında tespit edilen kökur nematodu: *Meloidogyne chitwoodi* (Goeldi, 1892, Nemata: Heteroderidae), 93". III. Bitki Koruma Kongresi (15-18 Temmuz, Van) Bildirileri, 380 s.