EVALUATION OF COFFEE GENOTYPES FOR ROOT-KNOT NEMATODE RESISTANCE

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ABSTRACT

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Meloidogyne konaensis causes severe damage to the root systems of *Coffea arabica* cv. Typica 'Guatemala' grown in Kona, Hawaii. Farmers currently employ grafting of the nematode tolerant *C. liberica* var. *dewevrei* 'Fukunaga' to *C. arabica* cv. Typica scions. Greenhouse experiments confirmed *C. liberica*'s tolerance to *M. konaensis* and *M. hapla* infection. Vigorous, healthy roots and rapid shoot growth occurred despite the presence of galls and high nematode populations. *Coffea purpurea* and *C. canephora* cv. Nemaya had reduced root-knot nematode populations in comparison to *C. arabica* cv. Typica although *C. purpurea* did not have the vigorous growth that was observed in *C. liberica* and *C. canephora*. Nematode populations were variable among *C. liberica* and *C. canephora* individuals, suggesting outcrossing and genetic variation among plants. The screening of *C. liberica* and *C. arabica* cultivars from Central America confirmed *C. liberica* had the least amount of root damage from *M. konaensis* infestation although *C. arabica* cvs. Caturra and Eritrean Moca demonstrated low nematode reproduction and moderate levels of tolerance to *M. konaensis*.

Key words: *Coffea*, coffee, *Meloidogyne konaensis*, resistance, root-knot nematode, rootstock.

RESUMEN

Cabos, R. Y. M., B. S. Sipes, C. Nagai, M. Serracin, and D. P. Schmitt. 2010. Evaluación de la resistencia al nematodo agallador en genotipos de café. Nematropica 40:191-202.

Meloidogyne konaensis causa daño severo al sistema radical de *Coffea arabica* cv. Típica 'Guatemala' que se cultiva en Kona, Hawaii. Los agricultores utilizan portainjertos de *C. liberica* var. *dewevrei* 'Fukunaga' tolerantes a los nematodos en conjunto con injertos de *C. arabica* cv. Típica. En experimentos de invernadero, se confirmó la tolerancia de *C. liberica* a *M. konaensis* y a *M. hapla*. A pesar de la presencia de agallas y de altas densidades de población de los nematodos, se observaron raíces vigorosas y saludables y crecimiento rápido de brotes. En *Coffea purpurea* y *C. canephora* cv. Nemaya se observó menor densidad de población de nematodos que en *C. arabica* cv. Típica, a pesar de que *C. purpurea* no tuvo el crecimiento vigoroso que se observó en *C. liberica* y *C. canephora*. La densidad de población de nematodos en *C. liberica* y *C. canephora* fue variable en las plantas individuales, indicando cruzamientos y variabilidad genética de las plantas. La evaluación de cultivares de *C. liberica* y *C. arabica* provenientes de Centroamérica confirmó que *C. liberica* presenta la menor cantidad de daño por *M. konaensis*, aunque los cultivares Caturra y Eritrean Moca de *C. arabica* mostraron baja reproducción de nematodos y niveles moderados de tolerancia a *M. konaensis*.

Palabras clave: café, *Coffea*, *Meloidogyne konaensis*, nematodo agallador, portainjertos, resistencia.

INTRODUCTION

Coffee, *Coffea arabica* L., is a bushy tree originating in the Ethiopian rift valley. The roasted seeds are of high value and used as a beverage. It is an important agricultural crop worldwide with exports valued at $641 million in 2009 (Anonymous, 2010). In

Hawaii (U.S.A.) the sales of coffee equaled $29.2 million (parchment equivalent basis) in the 2008/2009 season (Anonymous, 2009). Whereas many of the world's devastating coffee diseases like coffee rust, *Hemileia vastatrix*, are not found in Hawaii, farmers in the Kona district of Hawaii's Big Island have been plagued with a coffee decline that causes a discoloration of the leaves, wilting, defoliation, stunting, and tree death (Serracin *et al.*, 1999). D. P. Schmitt identified the cause of the decline as a unique root-knot nematode species, *Meloidogyne konaensis* (Eisenback *et al.*, 1994). This nematode parasitizes a wide range of plants in Hawaii, including vegetables and weeds commonly grown among coffee trees (Zhang and Schmitt, 1994). Infection by *M. konaensis* on *C. arabica* cv. Typica 'Guatemala' is characterized by sudden wilting, poor growth, few feeder roots, root galling and necrosis, as well as, swelling and corkiness of the main tap root (Serracin *et al.*, 1999). Schmitt (1996) estimated that each logarithmic increase in the *M. konaensis* population is associated with a 7% increase in damage to the plant. Under field conditions infected seedlings often die within five years after transplanting (Serracin, 2003).

Other *Coffea* species, such as *C. canephora* and *C. liberica*, are highly resistant to many of the diseases and pests that plague coffee cultivation including plant parasitic nematodes (Santos-Briones and Hernández-Sotomayor, 2006). Due to their undesirable cupping qualities, these species are best utilized as rootstocks for grafting with *C. arabica* scions. The use of resistant coffee rootstocks for the management of root-knot nematodes has been practiced on a large scale in Central and South America for over 35 years (Bertrand *et al.*, 2001). Seedlings of *C. arabica* are grafted to a *C. canephora* rootstock with a cleft graft at the hypocotyledon stage (Reyna, 1966). At a cost of $0.02 per grafted plant, grafting is an economically viable alternative for control of root-knot nematodes (Bertrand *et al.*, 2000).

New rootstocks are continually being developed by the Centro Agronómico Tropical de Enseñanza e Investigación (CATIE) in Costa Rica through the use of controlled pollination of individual trees in their germplasm collection (Bertrand *et al.*, 2000). One especially important cultivar is *C. canephora* cv. Nemaya, a cross of T3561 × T3751 (*C. canephora*), which is propagated on a large scale through the use of bioreactors for the multiplication and growth of somatic embryos (Bertrand *et al.*, 2000). Large field plots are also being established for economical seed production of this rootstock. Nemaya demonstrated 78% resistance to *Meloidogyne* spp. in El Salvador and 64% to *M. incognita* in a containerized trial (Bertrand *et al.*, 2000).

Other genotypes of *C. canephora* have also been employed successfully against root-knot nematodes. *Coffea arabica* cv. Caturra grafted on a rootstock of *C. canephora* had less plant mortality, lower gall index, and fewer plants with corky-root symptoms when compared to non-grafted Caturra in a field infested with *M. arabicida* (Bertrand *et al.*, 2002). *Coffea canephora* Apoatá is used as a rootstock in Brazilian plantations heavily infested with *M. incognita* and *M. paranaensis* (Campos and Villain, 2005). In a field study in Minas Gerais, Brazil, *C. arabica* grafted on to Apoatá rootstock produced higher coffee yields than non-grafted plants (Tomaz *et al.*, 2005).

The most promising control for *M. konaensis* in Hawaii has been the use of *C. liberica* var. *dewevrei* 'Fukunaga' as a rootstock for the *C. arabica* cv. Typica scion (Schmitt *et al.*, 2001). Zhang and Schmitt (1995a) reported a 1.4-2.6 fold reduction in the *M. konaensis* population when the Fukunaga genotype was used as a root-

stock. A more vigorous root system and greater yields were observed in a field trial with the use of the Fukunaga rootstock as compared to ungrafted *C. arabica* cv. Typica (Schmitt *et al.*, 2001).

Serracin and Schmitt (2002) recommended further evaluation of potential sources of host plant resistance to ensure long-term management of *M. konaensis*. Although most cultivars of *C. arabica* are highly susceptible to root-knot nematodes, a few cultivars have demonstrated some level of resistance or tolerance to certain *Meloidogyne* species. In a greenhouse study, Morera and López (1987) found that *C. arabica* cv. Anfillo T-3824 was moderately resistant to *M. exigua* in comparison to *C. arabica* cv. Catuai T-5267. *Coffea arabica* cvs. Caturra and Catuai proved to be nonhosts of a *M. javanica* isolate from California (Araya and Caswell-Chen, 1995). Several semi-wild Ethiopian accessions of *C. arabica*, screened against *M. incognita* isolates from Brazil and Guatemala, demonstrated complete nematode resistance (Anzueto *et al.*, 2001). Sub-spontaneous-derived progeny of *C. arabica* from Ethiopia displayed no corky-root symptoms after being inoculated with *M. arabicida* and *Fusarium oxysporum* (Bertrand *et al.*, 2002).

The objective of our study was to determine the effect of root-knot nematodes on *Coffea* genotypes with potential to be used as rootstocks by the Hawaiian coffee industry.

MATERIALS AND METHODS

Meloidogyne spp. on coffee genotypes

Seedlings of *C. arabica* cv. Typica 'Guatemala' 6432, *C. liberica* var. *dewevrei* 6622, *C. purpurea* 6792, and *C. canephora* cv. Nemaya with 8-10 leaves were obtained from the Kona Experiment Station and transferred to 15.5-cm-diameter clay pots containing a sterilized 2:1 mixture of soil and silica sand. Fifteen grams of Nutricote® 240-day slow release 13-13-13 fertilizer with micronutrients (Chisso-Asahi Fertilizer Co., Ltd. Tokyo, Japan) was applied twice at 8-month intervals. Plants were inoculated with *M. konaensis* or *M. hapla* eggs extracted from *C. arabica* cv. Typica plants grown in a greenhouse. *Meloidogyne konaensis* was initially obtained from *C. arabica* cv. Typica roots on a coffee plantation in Kealakekua, Kona, Hawaii and *M. hapla* was collected from *C. arabica* cv. Mokka roots on a coffee plantation in Kaanapali, Maui (Handoo *et al.*, 2005). Nematode eggs were collected by blending and sieving (Barker, 1985). Each coffee plant was inoculated with 10 ml aliquots containing 2,500 root-knot nematode eggs. Plants inoculated with different nematode species were isolated from each other on separate benches. A set of uninoculated plants was used as a control. Twenty-one plants of *C. arabica* cv. Typica, 9 plants of *C. liberica* var. *dewevrei*, and 18 plants each of *C. canephora* cv. Nemaya and *C. purpurea* were divided equally among the three nematode treatments (*M. konaensis*, *M. hapla*, and the uninoculated control). An unbalanced design was used because of unequal numbers of uniform-sized seedlings of the four genotypes. The plants were arranged in a completely randomized design inside a greenhouse with 70% shade in Hilo, Hawaii at an elevation of 442 m. The diurnal temperatures fluctuated from 21°C - 27°C. Plant heights were recorded at the beginning and end of the experiment. Due to the long life cycle of *M. konaensis* on coffee and the amount of time before symptoms become apparent, nematodes were allowed to develop for 15 months.

At termination, roots were detached at the soil line and evaluated. After removing excess soil and water, fresh root weights were obtained. The roots were blended in a 0.6% NaOCl solution for 15-30 seconds

(Barker, 1985). The egg suspension was quickly poured and rinsed through a 150-µm-pore sieve nested on a 20-µm-pore sieve. Nematode eggs were collected in 200 ml of water and counted in two aliquots, each containing 0.5 ml of the egg suspension.

The nematode reproductive factor (Rf) was calculated by dividing the final nematode population by the initial nematode population (Pf/Pi). Data were subjected to analysis of variance and means were compared using Duncan's multiple range test (Statistical Analysis System, 2003). The experiment was repeated once with the addition of 3 plants of *C. arabica* cv. Typica.

Meloidogyne konaensis on C. arabica c*ultivars*

Seeds from 13 *C. arabica* cultivars were obtained from various Central American coffee growing regions and germinated in the quarantine facility at the Waimea Arboretum on Oahu. Eight seedlings of each cultivar were placed in 15.5-cm-diameter clay pots containing a sterilized 1:1 mixture of soil and silica sand and arranged in a completely randomized design. Two lines of *C. liberica* containing 8 plants each were used as a comparison for tolerance to *M. konaensis*. When the plants contained 6-8 true leaves and reached 15-20 cm in height, they were inoculated with 10,000 *M. konaensis* eggs/pot. Five months later, the plants were inoculated again with 10,000 *M. konaensis* eggs/pot. Seven months after the first inoculation, all plants were examined for nematode damage. The shoots were evaluated for stunting and chlorosis. Each plant was rated on a scale from 0 to 5 with 0 being no visible symptoms and 5 being severe symptoms. The coffee plants were removed from their pots and gently immersed in water to remove the soil. The roots were evaluated for galling and necrosis using the same 0 to 5 rating system. Scores were compared by analysis of variance using the general linear models test and the mean separations were performed using the least significant difference analysis (SAS, 2003).

RESULTS

Meloidogyne spp. on coffee genotypes

The two experiments were analyzed separately due to differences in variation between the runs on all data ($P < 0.0001$) except for nematode eggs/g fresh root ($P \geq 0.1$). Contrasting behavior between the two *Meloidogyne* species occurred between the runs whereas in general, coffee genotypes behaved similarly to each other in both runs of the experiment.

No interaction between nematode and coffee species was observed. In the first run, *M. hapla* occurred at higher population densities than *M. konaensis* on all the coffee genotypes. The reproductive factor of *M. hapla* on *C. arabica* cv. Typica was greater ($P < 0.05$) than the Rf of *M. hapla* on *C. liberica* var. *dewevrei* and *C. purpurea* (Fig. 1A). The same trend was observed with the number of eggs/cm shoot and the final nematode population (J2 and eggs).

Meloidogyne hapla produced 108,800 J2 and eggs on *C. arabica* cv. Typica and 24,600 J2 and eggs on *C. purpurea*. *Coffea liberica* var. *dewevrei* also supported a low population density of *M. hapla* with 28,267 J2 and eggs. Wide variation within *C. liberica* occurred with the largest plants supporting the least number of nematodes, only 6,800 eggs after 15 months. *Coffea canephora* cv. Nemaya also had great variability in nematode population density ranging from 2,800 to 145,600 *M. hapla* J2 and eggs. Half of the Nemaya plants had an Rf lower than 3.1 although the Rf of the remaining Nemaya was greater than 44.0 (Fig. 2).

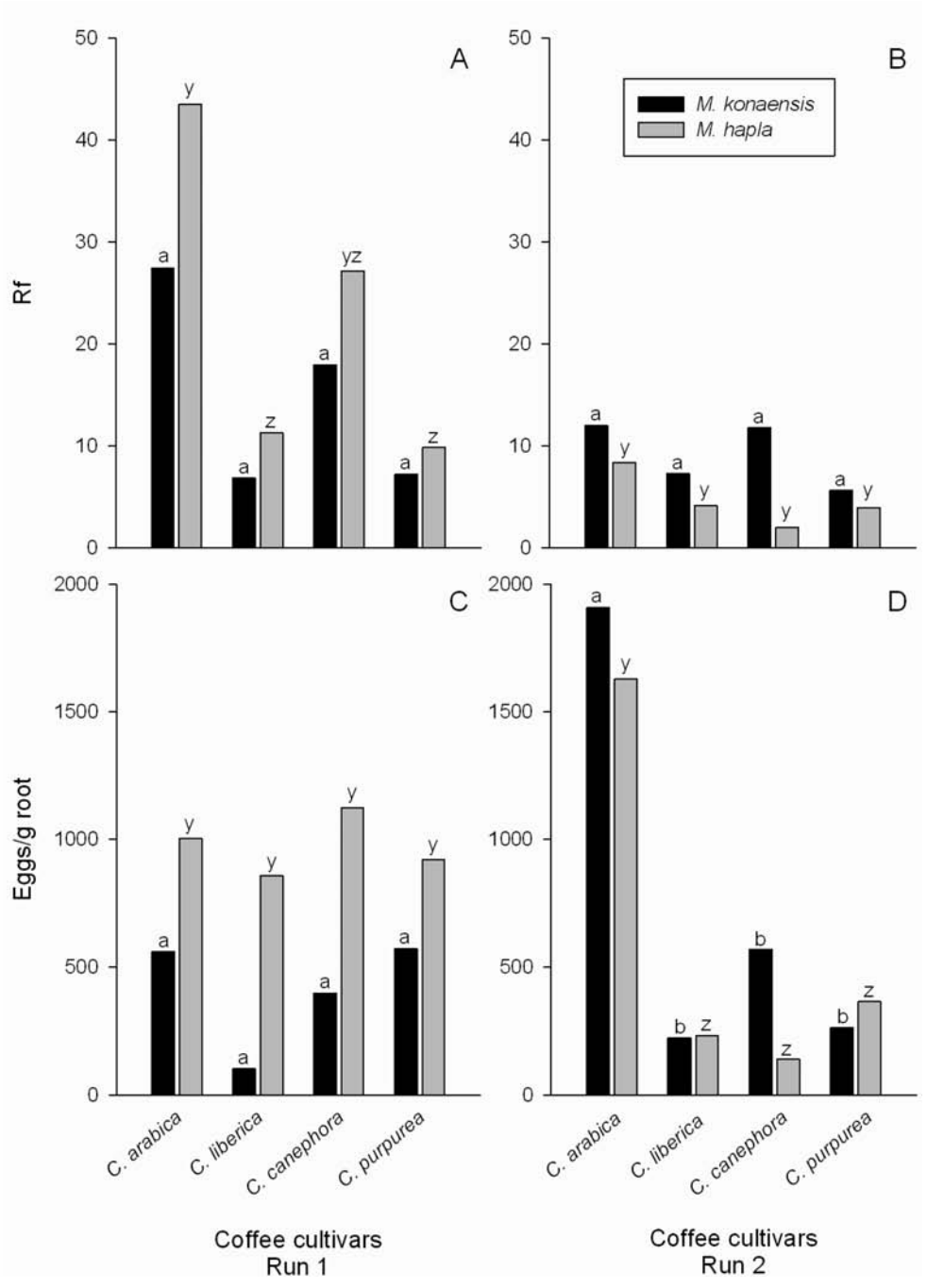

Fig. 1. Reproductive factor (Rf) of *Meloidogyne konaensis* and *M. hapla* (A, B) and the number of nematode eggs/g root (C, D) in *Coffea arabica* cv. Typica, *C. liberica* var. *dewevrei* Fukunaga, *C. canephora* cv. Nemaya, and *C. purpurea* 15 months after inoculation. Bars with the same letter are not different ($P > 0.05$) according to Duncan's multiple range test.

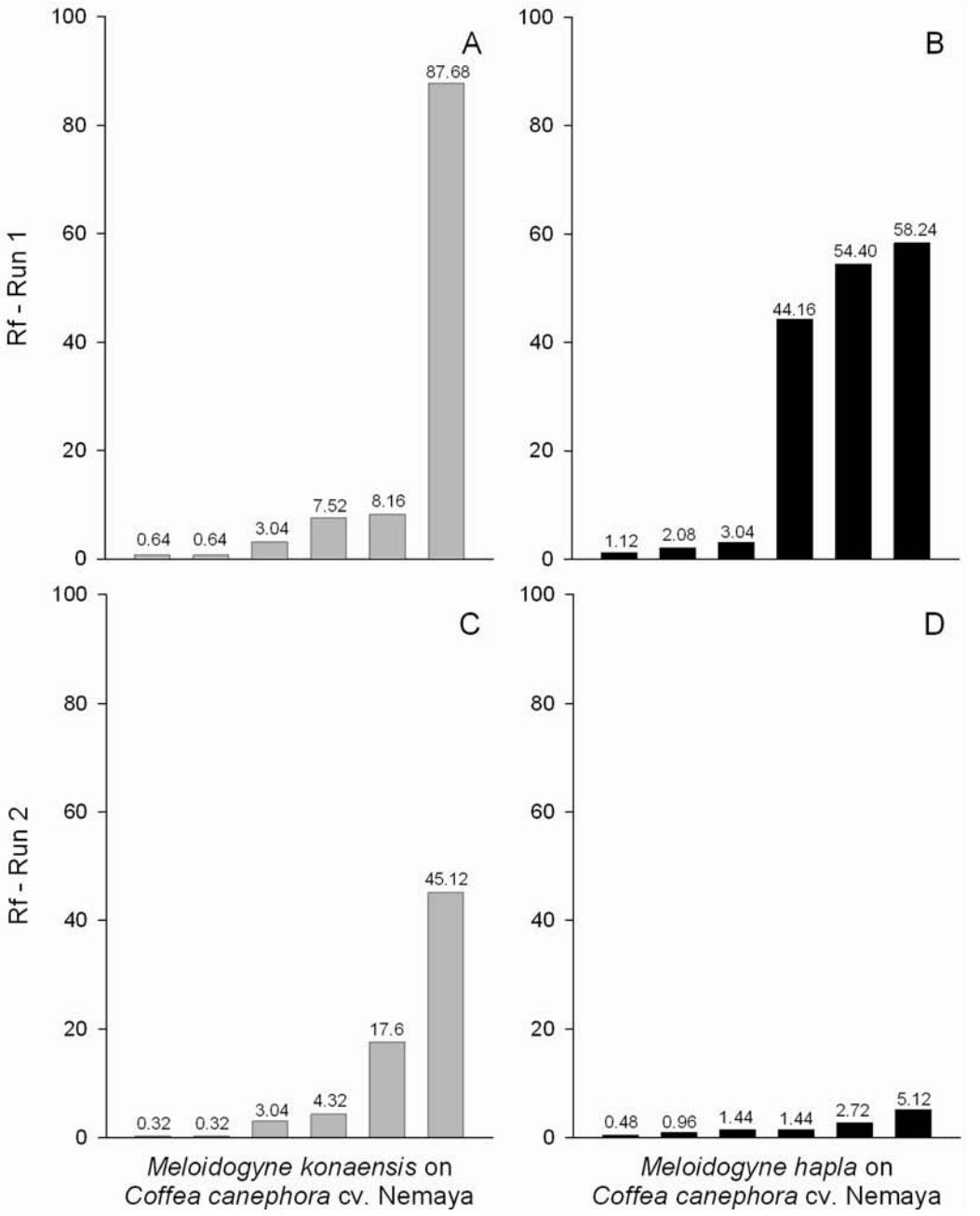

Fig. 2. Reproductive factor (Rf) o*f Meloidogyne konaensis* (A, C) and *M. hapla* (B, D) on *Coffea canephora* cv. Nemaya demonstrating the segregation of the F_2 generation. Each bar represents an individual plant.

Coffea arabica cv. Typica supported the largest number of *M. konaensis* (68,571) with *C. liberica* var. *dewevrei* and *C. purpurea* supporting the lowest number of *M. konaensis* (17,067 and 18,067, respectively). *Coffea canephora* cv. Nemaya had the greatest variation with a standard error of 85,794. The highest *M. konaensis* population recovered from Nemaya was 219,200 whereas the lowest was 1,600 J2 and eggs. These data fell into distinct classes of resistant (Rf < 5) and susceptible (Rf > 5) (Fig. 2).

Generally, all coffee genotypes were better hosts to *M. hapla* than to *M. konaensis*. The final population (Pf) of *M. konaensis* on *C. arabica* cv. Typica was greater (P = 0.03) than the Pf of *M. konaensis* on *C. liberica* var. *dewevrei* and *C. canephora* cv. Nemaya. No difference (P > 0.05) was observed in the number of nematode eggs/g root among species when inoculated with *M. konaensis* or *M. hapla* (Fig. 1C).

In the second run of the experiment, the population densities of *M. konaensis* were greater, although not statistically significant, than *M. hapla* among all of the coffee genotypes. Overall, nematode reproduction was lower in the second run as compared to the first. The highest nematode population density was on *C. arabica* cv. Typica for *M. konaensis* (30,000) and *M. hapla* (20,914). Greater variation was seen in nematode reproduction on *C. arabica* cv. Typica during this trial. *Coffea liberica* var. *dewevrei* infected with *M. hapla* had a lower final population than *C. arabica* cv. Typica, *C. purpurea,* or *C. canephora* cv. Nemaya inoculated with *M. hapla* (P < 0.05). The reproductive factor was not different (P > 0.05) among the coffee genotypes (Fig. 1B). The population of *M. hapla* eggs/g root was greater (P = 0.01) in *C. arabica* cv. Typica than in *C. liberica* var. *dewevrei*, *C. purpurea,* and *C. canephora* cv. Nemaya (Fig. 1D).

When the final nematode population was normalized by transforming to log10(x+1), *C. liberica* var. *dewevrei* inoculated with *M. konaensis* had a lower (P < 0.05) Pf than *C. arabica* cv. Typica although the untransformed Rf was not different. The population of *M. konaensis* eggs/g root differed (P < 0.01) between *C. arabica* cv. Typica and the other genotypes (Fig. 1D). *Coffea arabica* cv. Typica supported 1,909 *M. konaensis* eggs/g root compared to 570, 263, and 223 eggs/g root in *C. canephora* cv. Nemaya, *C. purpurea*, and *C. liberica* var. *dewevrei* respectively.

Plant growth differed among nematode and coffee species. *Coffea purpurea* plants inoculated with *M. konaensis* had a smaller root system than *C. liberica* var. *dewevrei* or *C. arabica* cv. Typica (P < 0.05) in the first experiment (Fig. 3). The root system of *C. purpurea* was also smaller than *C. arabica* cv. Typica in plants inoculated with *M. hapla* and uninoculated plants. Roots of uninoculated plants were robust with no visible galling or necrosis. Percentage plant growth was not different for all treatments but one (Fig. 4A). *Coffea liberica* var. *dewevrei* infected by *M. hapla* grew the most (P = 0.0130).

In the second run, the fresh weight of *C. canephora* cv. Nemaya roots inoculated with *M. hapla* was greater (P < 0.01) than *C. liberica* var. *dewevrei* and *C. arabica* cv. Typica inoculated with *M. hapla*. *Coffea arabica* cv. Typica infected with *M. konaensis* had a smaller fresh root weight (P < 0.01) than the other genotypes infected with *M. konaensis*. Plant growth (%) was greater (P < 0.01) in the un-inoculated *C. liberica* var. *dewevrei* than in the other treatments (Fig. 4B). In addition, *C. canephora* cv. Nemaya infected with *M. konaensis* grew more vigorously than all three *C. arabica* cv. Typica treatments.

M. konaensis on C. arabica *cultivars*

Galling on *C. liberica* roots inoculated with *M. konaensis* was lower (P < 0.01) than

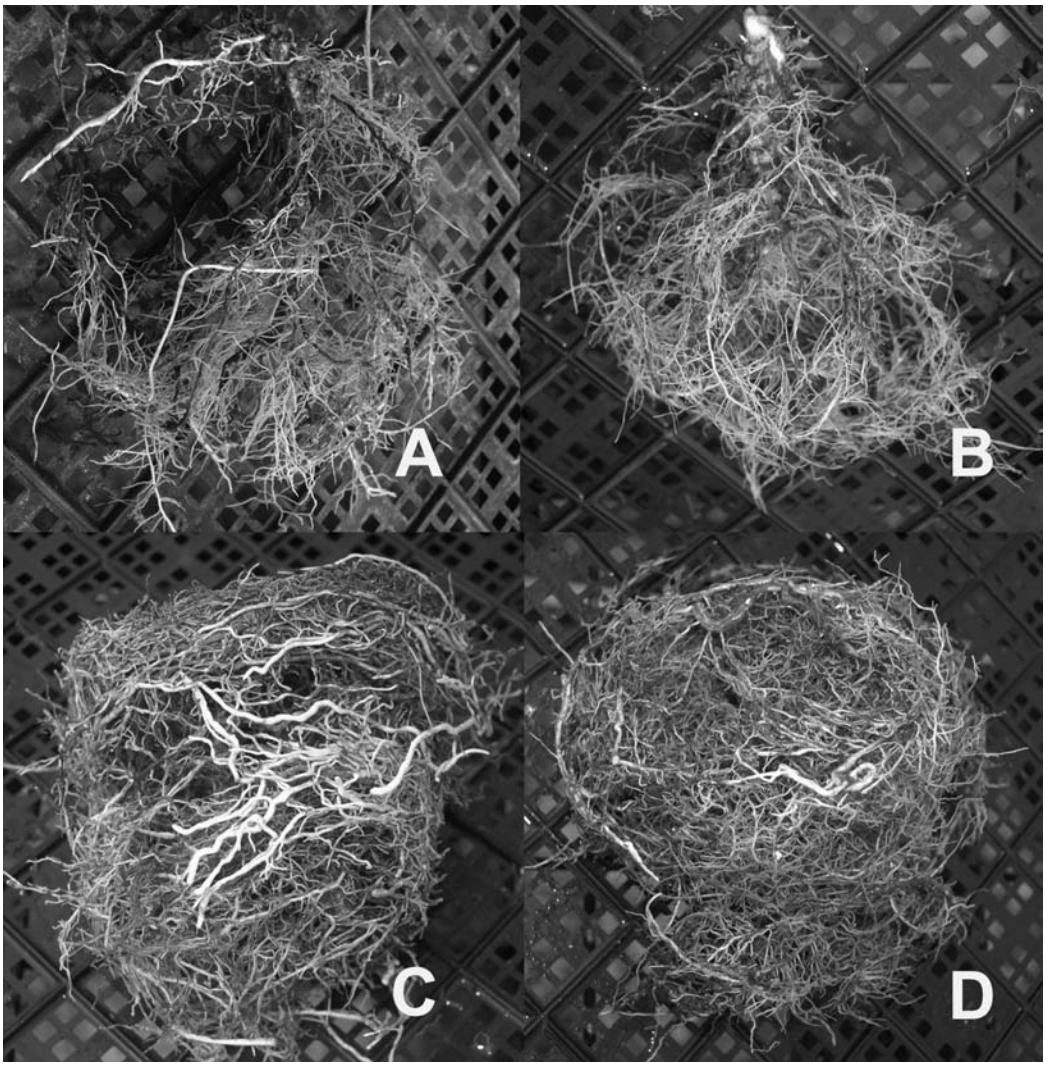

Fig. 3. Roots of *Coffea arabica* cv. Typica (A), *C. purpurea* (B), *C. liberica* var. *dewevrei* (C), and *C. canephora* cv. Nemaya (D) at 15 months after inoculation with *Meloidogyne konaensis*.

the galling observed on all the *C. arabica* cultivars inoculated with *M. konaensis* (Table 1). The *C. liberica* line collected from Kona had no visible galls in any of the 8 plants tested. The *C. liberica* line from Oahu had very few galls on the root system. The *C. arabica* cultivars with the least amount of galling were Caturra and Eritrean Moca. Root galling was highest on *C. arabica* cv. Pache 6788 and *C. arabica* cv. Bourbon Portillo. Cultivars Pache 6660, K7, and Pink Bourbon demonstrated the next highest level of galling.

Necrosis on the root system was mild on both lines of *C. liberica*, *C. arabica* cv. Eritrean Moca and *C. arabica* cv. Columnnaris (Table 1). Cultivars Caturra, Bourbon Pacas, and Mundo Novo had low levels of

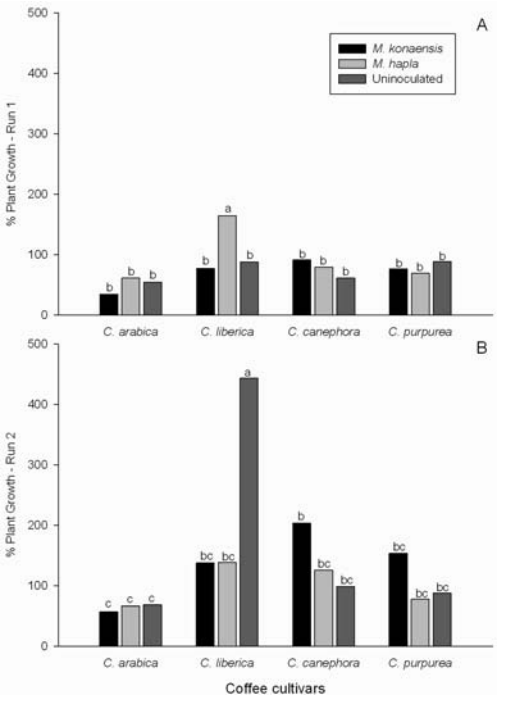

Fig. 4. Plant growth (%) of *Coffea arabica* cv. Typica, *C. liberica* var. *dewevrei*, *C. canephora* cv. Nemaya, and *C. purpurea* uninoculated or inoculated with *Meloidogyne konaensis* or *M. hapla* 15 months earlier. Bars with the same letter are not different (P > 0.05) according to Duncan's multiple range test.

necrotic lesions although higher (P < 0.0001) than *C. liberica*. The most severe necrosis was observed on *C. arabica* cvs. Pache 6788 and Bourbon Portillo. K7 and Bourbon Vermelho demonstrated high levels of necrosis. *Coffea arabica* cv. Pache 6660 had only moderate necrosis in the presence of a high amount of galling.

The lowest level of stunting was observed in the *C. liberica* line from Oahu whereas three of the eight *C. liberica* plants tested from the Kona line had very high levels of stunting (Table 1). The growth of most *C. arabica* cultivars were moderately reduced by the infestation of *M. konaensis*. Severe stunting occurred in *C. arabica* cv. Pache 6788 and *C. arabica* cv. Bourbon Portillo.

The amount of visible chlorosis differed among the cultivars (P < 0.0001). Chlorosis was mild in both *C. liberica* lines and *C. arabica* cv. Caturra whereas severe symptoms were observed in *C. arabica* cvs. Pache 6788 and Bourbon Portillo (Table 1). *Coffea arabica* cv. K7 had high levels of chlorosis on the leaves.

Six types of Bourbon were tested in this study and found to be moderately susceptible to *M. konaensis* with the exception of *C. arabica* cv. Bourbon Portillo which was extremely susceptible to the nematode (Table 1). The two lines of *C. arabica* cv. Pache were severely damaged by *M. konaensis*. Line 6660 was found to be highly susceptible and line 6788 extremely susceptible. With the exception of some stunting in the Kona line, both *C. liberica* lines were extremely resistant and tolerant to *M. konaensis* as determined by the rating system.

DISCUSSION

Nematode reproduction occurred on all of the inoculated coffee species and cultivars except several seedlings of Nemaya. *Coffea arabica* cv. Typica supported the highest populations of *M. konaensis* and *M. hapla*. Zhang and Schmitt (1995b) also found that *C. arabica* cv. Typica was the best host for the reproduction of *M. konaensis* among coffee genotypes whereas *C. liberica* cv. *dewevrei* supported moderately low numbers of the nematode. Likewise, in a field infested with *M. konaensis*, *C. arabica* cv. Typica had nematode population densities 1.4-2.6 times higher than *C. arabica* cv. Typica grafted on a *C. liberica* rootstock (Zhang and Schmitt, 1995b).

The response of the root system and the plant growth are the determining factors in a cultivar's tolerance to nematode infection. *Coffea arabica* cv. Typica is highly susceptible and relatively intolerant to *M.*

Table 1. Effects of inoculation with *Meloidogyne konaensis* on the root and shoot health of *Coffea liberica* and *C. arabica* cultivars.

	Root Evaluation		Shoot Evaluation	
Cultivar	Galling[y]	Necrosis[y]	Stunting[y]	Chlorosis[y]
C. arabica cv. Pache 6788	5.00 a[z]	5.00 a	5.00 a	5.00 a
C. arabica cv. Bourbon Portillo	4.88 a	5.00 a	5.00 a	5.00 a
C. arabica cv. Pache 6660	4.00 b	2.88 c	3.50 b	3.25 c
C. arabica cv. K7	4.00 b	4.00 b	3.00 b	4.00 b
C. arabica cv. Pink Bourbon	3.69 bc	3.06 c	2.25 c	2.38 e
C. arabica cv. Bourbon Vermelho	3.50 c	3.75 b	2.00 c	2.88 d
C. arabica cv. Bourbon SL	3.00 d	2.38 d	2.25 c	2.75 d
C. arabica cv. Mundo Novo	3.00 d	2.00 e	3.00 b	2.00 f
C. arabica cv. Bourbon	3.00 d	3.00 c	3.00 b	3.00 cd
C. arabica cv. Bourbon Pacas	3.00 d	2.00 e	2.00 c	3.00 cd
C. arabica cv. Columnnaris	2.81 d	1.88 ef	2.13 c	2.25 ef
C. arabica cv. Eritrean Moca	2.00 e	1.00 g	3.00 b	3.00 cd
C. arabica cv. Caturra	2.00 e	2.00 e	2.00 c	1.00 g
C. liberica (Oahu)	1.00 f	1.63 f	1.00 d	1.00 g
C. liberica (Kona)	0.00 g	1.00 g	2.13 c	1.00 g
LSD ($P \geq 0.05$)	0.33	0.35	0.72	0.35

[y]Observations are rated on a scale of 0-5 with 0 = none to 5 = severe.
[z]Means with the same letter are not different (P > 0.05) according to the least significant difference procedure (LSD).

konaensis and *M. hapla*. *Coffea arabica* cv. Typica roots were damaged to such an extent by the nematode that there were few feeding sites available. The nematodes caused extensive galling and root necrosis on *C. arabica* cv. Typica as has been reported (Zhang and Schmitt, 1995a). Poor plant growth resulting in a decrease in the nematode's food supply was also observed in *C. arabica* infected with *M. exigua* at high population densities (Di Vito *et al.*, 2001).

Among the other *C. arabica* cultivars, Caturra would appear to be the most promising due to its resistance and tolerance to *M. konaensis*. Eritrean Moca demonstrated the least amount of nematode reproduction within *C. arabica*, although its shoot growth and health were negatively affected by the nematode suggesting a low tolerance to infection. *Coffea arabica* cv. Columnnaris had less resistance to *M. konaensis* but a higher tolerance than Eritrean Moca.

Coffea liberica var. *dewevrei* was extremely tolerant to infection by *M. konaensis* and *M. hapla* producing plentiful healthy roots even with galling induced by root-knot nematode feeding. Zhang and Schmitt (1995a) also observed that *C. liberica* roots inoculated with *M. konaensis* produced a strong, abundant root system although galls were present. *Coffea canephora* cv. Nemaya grew vigorously in the presence of *M. konaensis* and *M. hapla*, with some individuals suppressing the nematode's growth and reproduction. *Coffea purpurea* was the

most consistently resistant species evaluated but lacked the vigorous growth characteristics of *C. canephora* cv. Nemaya and *C. liberica* var. *dewevrei*. *Coffea liberica* can grow as tall as 10 meters if not pruned (Bittenbender *et al.*, 2001).

Variability in nematode population can occur because of environmental conditions such as light, water and the composition of the soil mixture (Zhang and Schmitt, 1995b). However the variability seen in *C. liberica* var. *dewevrei* and *C. canephora* cv. Nemaya is likely due to genetic heterogeneity within the species. Serracin and Schmitt (2002) reported high resistance to *M. konaensis* in *C. liberica* var. *dewevrei* whereas Zhang and Schmitt (1995a) demonstrated moderate field resistance and suggested that the difference was due to genetic variability caused by cross-pollination of the mother trees (Serracin and Schmitt, 2002). Rootstock germplasm needs to be managed properly to maintain its high level of effectiveness. Due to open pollination of *C. canephora* in Central America, unselected rootstocks have significantly lower nematode resistance levels from years of outcrossing (Bertrand *et al.*, 2000). Some variability in rootstock resistance has previously been observed in Hawaii (Serracin and Schmitt, 2002). DNA fingerprinting of *C. liberica* var. *dewevrei* trees from various locations in Kona and Oahu revealed only a 0.68 similarity among trees, suggesting that the trees were not closely related (Ming *et al.*, personal communication). Since *C. liberica* is self-incompatible, it may have crossed with *C. canephora* resulting in progeny that are more susceptible to *M. konaensis*. The *C. canephora* cv. Nemaya seedlings were from an F_2 population which is probably segregating giving wide variation in nematode resistance levels. Nemaya and to some extent *C. liberica* var. *dewevrei*, showed great variability in their response to root-knot nematode infection. Plants with extremely high resistance levels should be vegetatively propagated or cloned by in vitro techniques to ensure acceptable levels of resistance are deployed in the field. As long as these techniques are employed or controlled pollination is practiced, grafting *C. arabica* cv. Typica scions on to *C. liberica* var. *dewevrei* rootstocks remains the most effective method of host plant resistance for Hawaii coffee growers.

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