GREENHOUSE EVALUATION OF *CAPSICUM* ROOTSTOCKS FOR MANAGEMENT OF *MELOIDOGYNE INCOGNITA* ON GRAFTED BELL PEPPER

N. Kokalis-Burelle*, M. G. Bausher, and E. N. Rosskopf

USDA, ARS, U.S. Horticultural Research Laboratory, Fort Pierce, FL 34945. *Corresponding author: nancy.burelle@ars.usda.gov

ABSTRACT

Kokalis-Burelle, N., M. G. Bausher, and E. N. Rosskopf. 2009. Greenhouse evaluation of *Capsicum* rootstocks for management of *Meloidogyne incognita* on grafted bell pepper. Nematropica 39:121-132.

The growth, development, and nematode susceptibility of various rootstock genotypes grafted to a commercial bell pepper variety scion were evaluated in a series of greenhouse experiments. Nine rootstocks including 'Caribbean Red Habanero', 'PA-136', 'Keystone Resistant Giant', 'Yolo Wonder', 'Carolina Wonder', 'Charleston Hot', 'Mississippi Nemaheart', 'Carolina Cayenne', and 'Charleston Belle', were grafted to the commercial variety 'Aristotle' as a scion, and inoculated with *Meloidogyne incognita*. 'Aristotle' ungrafted and 'Aristotle' self-grafted plants were included as controls. Graft compatibility was assessed by measuring plant growth, while nematode infestation was assessed using a gall index, and extraction and quantification of juveniles from roots and soil. Stem weight of the scion 'Aristotle' was impacted by the use of different rootstocks, and root weight of the rootstocks varied, however, no rootstock/scion incompatibility occurred. The rootstocks 'Charleston Hot', 'Carolina Wonder', 'Charleston Belle', 'Mississippi Nemaheart' and 'Carolina Cayenne' were consistently resistant to galling by *M. incognita* in all experiments, while 'Aristotle' ungrafted, 'Aristotle' self-grafted, 'PA-136', and 'Caribbean Red Habanero' were consistently susceptible to galling. Cultivars 'Yolo Wonder' and 'Keystone Resistant Giant' varied in their responses, with reduced galling in one experiment. Grafting a commercial bell pepper variety scion on nematode resistant rootstock has potential to reduce damage caused by *M. incognita* and contribute to root-knot nematode management as a component in sustainable crop production systems.

Key words: bell pepper, *Capsicum annuum*, graft compatibility, *Meloidogyne incognita*, root-knot nematode, rootstock.

RESUMEN

Kokalis-Burelle, N., M. G. Bausher, and E. N. Rosskopf. 2009. Evaluación en invernadero de portainjertos de *Capsicum* para el manejo de *Meloidogyne incognita* en pimiento injertado. Nematropica 39:121-132.

Se evaluó el crecimiento, desarrollo y susceptibilidad a nematodos de varios genotipos de portainjerto con injerto de una variedad comercial de pimiento, en una serie de experimentos de invernadero. Se utilizaron nueve portainjertos ('Caribbean Red Habanero', 'PA-136', 'Keystone Resistant Giant', 'Yolo Wonder', 'Carolina Wonder', 'Charleston Hot', 'Mississippi Nemaheart', 'Carolina Cayenne' y 'Charleston Belle') con el injerto de la variedad comercial 'Aristotle', inoculados con *Meloidogyne incognita*. Los testigos fueron 'Aristotle' sin injertar y 'Aristotle' injertado sobre sí mismo. Se evaluó la compatibilidad del injerto con base en el crecimiento de la planta. La susceptibilidad a nematodos se evaluó con base en el índice de agallamiento y el número de nematodos presentes en las raíces y el suelo. Los diferentes portainjertos afectaron el peso del tallo del injerto 'Aristotle', y se observó variación en el peso de la raíz de los diferentes portainjertos, pero no se observó incompatibilidad de injerto. Los portainjertos 'Charleston Hot', 'Carolina Wonder', 'Charleston Belle', 'Mississippi Nemaheart' y 'Carolina Cayenne' fueron consistentemente resistentes al agallamiento por *M.*

incognita en todos los experimentos, mientras que 'Aristotle' sin injertar, 'Aristotle' injertado, 'PA-136' y 'Caribbean Red Habanero' fueron consistentemente susceptibles al agallamiento. Se observó respuesta variable en los portainjertos 'Yolo Wonder' y 'Keystone Resistant Giant', con reducción en el agallamiento en un experimento. El injerto de una variedad comercial en un portainjerto resistente a nematodos tiene el potencial de reducir el daño causado por *M. incognita* y es una herramienta para el manejo de nematodos agalladores en sistemas de producción sostenibles.

Palabras clave: *Capsicum annuum*, compatibilidad de injerto, *Meloidogyne incognita*, nematodo agallador, pimiento, portainjerto.

INTRODUCTION

The southern root-knot nematode *Meloidogyne incognita* is a serious pest in the southeastern U.S.A. on many solanaceous crops including pepper, tomato and eggplant. Currently, soil fumigation is the most commonly used method for controlling nematodes, soilborne pathogens, and weeds in the U.S.A. and other countries. Environmental concerns with all soil fumigants have driven research efforts to develop alternative pest management strategies (Ristaino and Thomas, 1997; Rosskopf *et al.*, 2005). Using germplasm resistant to major soilborne diseases and pests can be an effective way to manage pathogens and parasitic nematodes (Buena *et al.,* 2006) in tropical and subtropical climates. The ability to produce germplasm, which contains horticulturally acceptable characteristics with resistance to a wide range of pests, is difficult in plants such as pepper, grown under high soil temperatures in tropical and subtropical climates (Djian-Caporalino *et al.,* 1999; Thies and Fery, 2000). Desirable horticultural characteristics in bell pepper include high yielding varieties that produce four-lobed, blocky fruit, and resistance to important pathogens such as southern root-knot nematode and *Phytophthora capsici.*

The use of resistant rootstocks for control of soilborne pests in solanaceous crops has helped eliminate the use of methyl bromide in several countries where weed pressure does not play a significant role in yield response (Besri, 2007; Yilmaz *et al.,* 2007). Grafting desirable scion varieties onto resistant rootstocks for control of *M. incognita* on pepper has been proposed as a viable alternative to methyl bromide fumigation for control of this pest (Anonymous, 2007; Lee, 1994; Oda, 1999; Oka *et al.,* 2004; Kubota *et al.*, 2008). Few if any of the commercially acceptable horticultural varieties of bell pepper have resistance to *M. incognita,* but have other desirable traits. Grafting allows for production of commercially acceptable varieties on rootstocks that have some level of resistance or tolerance to soilborne pathogens including nematodes.

The goal of this research was to evaluate nine *Capsicum* cultivars as rootstocks for the commercial bell pepper cultivar scion 'Aristotle'. Specific objectives were to assess effects of grafting on plant growth, on *M. incognita* and beneficial nematode populations in soil and roots, and on root disease and levels of susceptibility to galling by *M. incognita.*

MATERIALS AND METHODS

A series of greenhouse experiments was conducted to evaluate nine *Capsicum* rootstocks for effects on plant growth, nematode populations, and resulting disease symptoms. Four nematode resistant pepper rootstocks, which were released by the USDA, ARS were evaluated; 'Charleston

Belle', 'Charleston Hot', 'Carolina Wonder', and 'Carolina Cayenne' (Fery *et al.*,1998; Fery and Thies, 1998). Also evaluated was 'Mississippi Nemaheart', which was released by the Mississippi Agricultural Experiment Station in 1966 (Hare, 1966), and was the genetic basis for imparting nematode resistance in the varieties released by USDA, ARS. The susceptible varieties 'Keystone Resistant Giant' and 'Yolo Wonder', which were used as one of the parents in the backcross breeding procedure that produced 'Charleston Belle', and 'Carolina Wonder' respectively, were also evaluated (Fery *et al.*, 1998). 'PA-136', a highly susceptible variety and a sibling of 'Carolina Cayenne' (Thies *et al.,* 1998), and 'Caribbean Red Habanero' (Sieger Seed Company, Holland, MI), a variety with unknown resistance were also tested (Dukes *et al.,* 1997; Thies and Fery, 1998). 'Aristotle' (Seminis, Inc., Saint Louis, MO) was used as the scion for all nine rootstocks, and was included as both ungrafted and self-grafted controls. Use of 'Aristotle' was based on industry popularity as a high-yielding variety that produces four-lobed fruit, and which has some reported tolerance to *Phytophthora capsici* (Babadoost and Islam, 2004).

All scion and rootstock material were seeded and grown until ready for grafting in a standard greenhouse at the USDA, ARS, U.S. Horticultural Research Lab, Ft. Pierce, FL, under 24-30°C day/22-24°C night conditions. Seeds were germinated for rootstocks and scions in trays with 105 cells, with a cell volume of 20.85 ml (Landmark Plastics, Akron Ohio). Growth medium consisted of washed sand and Fafard germination mix (Conrad Fafard, Inc., Agawam, MA) (pH 7.2) in a 50:50 ratio. When plants reached a stem diameter of approximately 1.5 mm, all of the rootstocks were grafted by hand to 'Aristotle' as a scion and secured using graft clips (Bato BV, Zevenbergen, The Netherlands). The newly grafted plants were transferred to an annealing chamber at 26°C, 95% humidity and 95 µmols $m^{-2} s^{-1}$ light. After ten days of annealing growth, the plants were transferred to the greenhouse where the study was to be conducted. Self-grafted and ungrafted 'Aristotle' control plants were subjected to the same conditions as all other rootstocks grafted to 'Aristotle'. Plants were fertilized as needed with a dilute solution of Peters 20-20-20 (J. R. Peters, Inc, Allentown, PA).

The first experiment was arranged in a completely randomized design with four replications and 8-17 plants/replication. Plants were inoculated by pipetting an aqueous solution containing approximately 650 *M. incognita* eggs/ml onto each root system. Inoculum was delivered in 1 ml into a slight depression in the growth medium near the stem in each container. Nematode inoculum was extracted from pure cultures maintained on tomato (*Solanum lycopersicum*), grown in sand in greenhouse cultures. Plants were hand watered from below and grown for 67 days, after which plant growth, nematode, and disease data were collected. Eight plants from each replication were evaluated for growth and disease for a total of 32 plants/treatment, however, nematodes were extracted only from two plants per replication for a total of eight plants per treatment.

A second set of experiments was performed to more stringently assess nematode resistance, and effects of rootstocks on populations in roots and soil. Following the graft annealing process, plants were grown in larger containers in order to enable extraction of nematodes from soil, and more appropriately assess plant growth in addition to graft compatibility. Seed were planted, and grafting was performed as described above. Following the annealing process, plants were potted into 10 cm diameter plastic pots containing a mixture of sand:peat (3:1), inoculated with 1000 *M. incognita* eggs/pot as described above, maintained, and fertilized as described above. Plants were arranged on a greenhouse bench in a completely randomized design with five replications. Plants were grown for 70 days in both experiment 2 and experiment 3.

At the end of all experiments, plant growth measurements were recorded including fresh root and stem weight, and stem diameter above and below the graft union. In the second set of experiments, fruit weight was also assessed. In all experiments, roots were evaluated for galling and root condition, and nematodes were extracted from roots using Baermann funnels, and counted. Nematodes were also extracted from soil in the second set of experiments, and beneficial (microbivorous) nematodes from both soil and roots were assessed. Root condition was used as a general indicator of root disease and was assessed using a subjective scale of 1 to 5 with 1 = 0% to 20% discolored roots, 2 = 21% to 40%, 3 = 41% to 60%, 4 = 61% to 80%, and 5 = 81% to 100%. Root galling was assessed using a root gall index based on a scale of 1 to 10, with one representing no galls and 10 representing severe (100%) galling (Zeck, 1971).

Data for all experiments were subjected to analysis of variance using the general linear models procedure (GLM), with Levene's test for homogeneity of variance performed on experiments 2 and 3, and mean separation for all experiments performed using the least significant difference procedure (LSD) (SAS version 9.12, Carey, NC). Differences are reported at $P \leq 0.05$.

RESULTS AND DISCUSSION

The initial experiment was performed to determine compatibility between the scion and rootstocks of interest for further testing. Plants in this study were inoculated with nematodes and assessed to gain preliminary indications of susceptibility and durability of documented resistance following grafting. Stem diameter changes below or above the graft union can be an indication of physiological changes due to the cellular interaction of the two genotypes. In this experiment there were no differences in stem diameter above the graft union among rootstocks, indicating that the 'Aristotle' scion is not adversely affected by the rootstocks (data not shown). The rootstock cultivars that supported the most prolific growth of the scion, reflected as stem weight, were 'Caribbean Red Habanero', 'Carolina Wonder', and 'Carolina Cayenne'. The varieties 'PA-136', 'Aristotle' self-grafted, and 'Yolo Wonder' supported the least growth by this measure (Table 1). Growth of the root system was highest in the 'Aristotle' ungrafted plants (Table 1). 'PA-136' had the lowest root weight of all the rootstocks with 48% less growth than the 'Aristotle' ungrafted root system.

Root galling was highest on 'Aristotle' grafted, 'Caribbean Red Habanaro', and 'Yolo Wonder', and lowest on 'Charleston Hot' 'Carolina Wonder' 'Charleston Belle', 'Mississippi Nemaheart' and 'Carolina Cayenne' rootstocks (Table 1). All of the previously reported resistant rootstock cultivars had little galling by *M. incognita*. 'Aristotle' self-grafted and 'Aristotle' ungrafted sustained a higher level of galling than 'Charleston Hot', 'Carolina Wonder', 'Charleston Belle', 'Mississippi Nemaheart', and 'Carolina Cayenne' (Table 1). 'Aristotle' self-grafted also had significantly higher galling than 'Aristotle' ungrafted, indicating that the grafting process may stress susceptible varieties, inducing higher levels of galling than in non-stressed plants (Table 1). 'PA-136' had the highest num-

Table 1. Effects of grafting and inoculation with *Meloidogyne incognita* on plant growth, *M. incognita* J2 isolated from roots, and galling on *Capsicum* rootstocks grafted with 'Aristotle' bell pepper as a scion.

	Stem weight	Root weight	*M. incognita*/g root	Gall rate[Y]
'Aristotle' ungrafted	3.93 abc[Z]	4.16 a	0.39 b	1.58 b
'Aristotle' self-grafted	3.60 c	3.47 c	0.00 b	2.13 a
'PA-136'	3.59 c	1.99 f	32.20 a	1.56 b
'Caribbean Red Habanero'	4.20 a	2.27 ef	17.13 ab	2.17 a
'Yolo Wonder'	3.53 c	3.69 bc	2.84 b	2.21 a
'Keystone Resistant Giant'	3.65 bc	3.50 c	0.41 b	1.06 bc
'Charleston Hot'	4.04 ab	2.19 ef	0.00 b	0.09 e
'Carolina Wonder'	4.25 a	3.51 c	0.60 b	0.63 cd
'Charleston Belle'	3.66 bc	3.85 ab	0.00 b	0.50 de
'Mississippi Nemaheart'	3.90 abc	2.59 d	0.00 b	0.36 de
'Carolina Cayenne'	4.19 a	2.40 de	0.00 b	0.11 de
LSD (0.05)	0.42	0.31	21.00	0.53

[X] All rootstocks were grafted to 'Aristotle' as the scion cultivar with the exception of 'Aristotle' ungrafted, which was included as a control.
[Y] Zeck's rating scale, 0-10.
[Z] Means followed by the same letter do not differ at $P \leq 0.05$.

ber of *M. incognita* J2 extracted/g root tissue and, although it had higher gall ratings than the resistant varieties, galling for 'PA-136' did not differ from the 'Aristotle' ungrafted, which had lower numbers of J2 isolated from roots (Table 1). This may indicate some level of tolerance in this rootstock variety. Although galling may be reduced, populations of *M. incognita* in soil could be increased, potentially making use of this rootstock less desirable for long-term management of *M. incognita*.

Levene's homogeneity of variance test failed for data in experiments 2 and 3, which were identical. Therefore, the data were analyzed separately, and are presented separately for each study. In these experiments, which were performed in larger containers to better assess effects on nematode populations in roots and soil in addition to resistance, rootstocks varied in their effects on growth of the scion including stem weight, fruit weight and stem caliper above the graft (Table 2). However, even though the 'Aristotle' ungrafted plants had significantly higher stem weight and stem diameter above the graft than several other rootstocks, none of the rootstock/scion combinations appeared to be incompatible. Interestingly, stem diameter above the graft union was reduced in many rootstocks that are discussed later as highly resistant to galling (Table 4). In several varieties, although stem weight was reduced, fruit weight was increased compared to the 'Aristotle' ungrafted (Table 2). Root weight varied among the rootstocks (Table 2).

'Caribbean Red Habanero' had the highest number of *M. incognita* and microbivorous nematodes isolated from both soil and roots in experiment 2, as well as one of the highest gall ratings, and most diseased root condition ratings of any rootstock tested (Table 3). Rootstocks can be clearly characterized as either resistant or suscep-

Table 2. Effects of grafting and inoculation with *Meloidogyne incognita* on plant growth in experiment 2. Differences in stem diameter above and below the graft can be used as a measure of graft compatibility.

	Stem weight (g)	Fruit weight (g)	Root weight (g)	Stem diameter 0.5 cm above graft (mm)	Stem diameter 0.5 cm below graft (mm)
'Aristotle' ungrafted	43.53 a[z]	77.55 b	35.40 ab	8.76 a	8.88 bc
'Aristotle' self-grafted	39.07 abc	98.86 ab	32.15 abcd	8.53 ab	10.00 a
'PA-136'	37.95 bc	115.06 a	20.00 e	7.93 bc	7.70 de
'Caribbean Red Habanero'	39.29 ab	99.31 ab	23.76 de	8.30 ab	7.86 de
'Yolo Wonder'	38.03 bc	108.82 a	34.11 abc	7.80 bcd	8.32 cd
'Keystone Resistant Giant'	37.32 bc	117.15 a	30.27 abcd	7.76 bcd	9.54 ab
'Charleston Hot'	37.14 bc	123.70 a	25.42 cde	7.10 de	7.20 ef
'Carolina Wonder'	41.02 ab	113.07 a	34.49 abc	7.76 bcd	8.90 bc
'Charleston Belle'	40.64 ab	106.82 ab	38.49 a	6.68 e	8.08 cde
'Mississippi Nemaheart'	37.79 bc	99.93 ab	27.76 bcde	7.17 cde	7.87 de
'Carolina Cayenne'	34.17 c	115.97 a	20.40 e	6.81 e	6.68 f
LSD (0.05)	4.91	29.96	9.39	0.78	0.98

[y]All rootstocks were grafted to 'Aristotle' as the scion cultivar with the exception of 'Aristotle' ungrafted, which was included as a control.
[z]Means with the same letter are not significantly different.

Table 3. Effects of grafting and inoculation with *Meloidogyne incognita* on *M. incognita* J2 isolated from soil and roots, microbivorous (free-living) nematodes isolated from soil and roots, and galling on *Capsicum* rootstocks grafted with 'Aristotle' bell pepper as a scion in experiment 2.

	M. incognita /100 cc soil	Microbivorous[W] /100 cc soil	*M. incognita* /g root	Microbivorous /g root	Gall rate[X]	Root condition[Y]
'Aristotle' ungrafted	2.27 b[Z]	376.5 b	16.73 ab	13.78 b	3.28 c[Z]	1.10 cd
'Aristotle' self-grafted	13.61 b	943.5 b	43.29 ab	19.99 b	5.18 a	1.70 bc
'PA-136'	6.80 b	712.2 b	25.67 ab	19.00 b	5.16 a	1.50 c
'Caribbean Red Habanero'	43.09 a	1873.4 a	58.97 a	108.30 a	5.12 a	2.56 a
'Yolo Wonder'	6.80 b	1102.2 ab	34.10 ab	35.07 b	3.88 bc	1.64 bc
'Keystone Resistant Giant'	13.61 b	451.3 b	34.22 ab	14.42 b	5.04 ab	0.94 cd
'Charleston Hot'	0.00 b	281.2 b	8.75 b	20.33 b	0.18 d	2.40 ab
'Carolina Wonder'	9.07 b	462.7 b	1.97 b	8.13 b	0.02 d	0.28 d
'Charleston Belle'	6.80 b	337.9 b	0.22 b	12.15 b	0.24 d	0.54 d
'Mississippi Nemaheart'	0.00 b	383.3 b	1.72 b	19.00 b	0.10 d	0.60 d
'Carolina Cayenne'	0.00 b	530.7 b	1.11 b	18.65 b	0.12 d	0.88 cd
LSD (0.05)	25.56	827.31	47.17	38.91	1.18	0.83

[W]All rootstocks were grafted to 'Aristotle' as the scion cultivar with the exception of 'Aristotle' ungrafted, which was included as a control.
[X]Gall rates based on Zeck's gall index.
[Y]Root condition rating based on 0 = no discoloration, 4 = completely rotted.
[Z]Means with the same letter are not significantly different.

Table 4. Effects of grafting and inoculation with *Meloidogyne incognita* on plant growth in experiment 3. Differences in stem diameter above and below the graft can be used as a measure of graft compatibility.

	Stem weight (g)	Fruit weight (g)	Root weight (g)	Stem diameter 0.5 cm above graft (mm)	Stem diameter 0.5 cm below graft (mm)
'Aristotle' ungrafted	39.60 ab[Z]	139.40 ab	15.17 ab	5.22 b	6.42 abc
'Aristotle' self-grafted	39.60 ab	115.80 b	13.10 b	5.50 ab	6.92 ab
'PA-136'	34.40 b	124.00 ab	7.94 e	5.16 b	5.80 cd
'Caribbean Red Habanero'	36.80 ab	129.60 ab	10.30 cde	5.96 a	5.58 cd
'Yolo Wonder'	36.80 ab	141.80 ab	12.81 bc	5.22 b	7.00 a
'Keystone Resistant Giant'	40.60 a	132.00 ab	16.76 a	5.36 b	6.92 ab
'Charleston Hot'	38.40 ab	133.40 ab	9.98 de	5.48 ab	5.86 cd
'Carolina Wonder'	37.60 ab	135.00 ab	12.57 bcd	5.24 b	6.12 bcd
'Charleston Belle'	40.20 a	149.20 a	14.89 ab	5.66 ab	7.06 a
'Mississippi Nemaheart'	38.00 ab	129.00 ab	10.38 cde	5.34 b	6.10 bcd
'Carolina Cayenne'	36.20 ab	134.00 ab	9.72 e	5.22 b	5.40 d
LSD (0.05)	5.28	29.16	2.64	0.54	0.86

[Y]All rootstocks were grafted to 'Aristotle' as the scion cultivar with the exception of 'Aristotle'. ungrafted, which was included as a control.
[Z]Means with the same letter are not significantly different.

tible with respect to galling. Resistant rootstocks included 'Charleston Hot', 'Carolina Wonder', 'Charleston Belle', 'Mississippi Nemaheart', and 'Carolina Cayenne' (Table 3). Susceptible rootstocks include 'Aristotle' ungrafted, 'Aristotle' grafted, 'PA-136', 'Caribbean Red Habanero', 'Yolo Wonder', and 'Keystone Resistant Giant'. Within the susceptible rootstocks, 'Yolo Wonder' and 'Aristotle' ungrafted were less susceptible than the other rootstocks, but not sufficiently so to be categorized as resistant (Table 3). Most of the highly resistant cultivars also had good root condition ratings with the exception of 'Charleston Hot', which was not different from 'Caribbean Red Habanero' (Table 3). Again, as in experiment 1 the 'Aristotle' self-grafted had a significantly higher gall rating then the 'Aristotle' ungrafted control. 'Caribbean Red Habanero' was the only rootstock that had significantly higher numbers of microbivorous nematodes isolated from soil and roots (Table 3). This could be due to 'Caribbean Red Habanero' having the worst root condition ratings, indicating significant root decay, and leading to increased microbial activity and increased numbers of microbivorous nematodes.

In experiment 3, rootstocks varied in their effects on plant growth with 'PA-136' and 'Carolina Cayenne' again having the lowest root weights (Table 4). However, stem weight did correlate more directly with fruit weight in this test, with larger plants having higher fruit weight. Several of the resistant rootstocks had lower root weights than the controls, and susceptible rootstocks (Table 4). This can be explained by the fact that high nematode infestation can manifest itself in either greatly reduced root growth and increased root deterioration, leading to lower root weights, or heavier root systems due to high levels of galling. As seen in previous tests, no rootstock/scion combination was incompatible.

'PA-136' had the highest number of *M. incognita* in soil and roots (Table 5), which differed from previous results where 'Caribbean Red Habanero' was the most susceptible (Table 2). 'Caribbean Red Habanero' had the second highest number of *M. incognita* isolated from both soil and roots, although it did not differ from either the 'Aristotle' self-grafted or 'Aristotle' ungrafted controls (Table 5). 'Carolina Cayenne' had the lowest numbers of *M. incognita* J2 isolated from both roots and soil (Table 5), which were similar to previous results (Table 3).

Rootstocks could again be characterized into two distinct categories with respect to galling. Resistant rootstocks that were consistent with experiment 2 were 'Charleston Hot', 'Carolina Wonder', 'Charleston Belle', 'Mississippi Nemaheart', and 'Carolina Cayenne' (Table 5), with 'Keystone Resistant Giant' also resistant in this test, and 'Yolo Wonder' and 'Aristotle' self-grafted intermediate. Consistently susceptible rootstocks were 'PA-136', and 'Caribbean Red Habanero' (Table 5). Most of the resistant cultivars also had good root condition ratings with the exceptions of 'Carolina Cayenne', 'Charleston Hot', and 'Keystone Resistant Giant', which were not different from 'Caribbean Red Habanero', which again had the poorest root condition rating of all rootstocks (Table 5). 'Caribbean Red Habanero' had higher numbers of microbivorous nematodes isolated from roots, and high (more diseased) root condition ratings (Table 5). No difference in gall rating was found between 'Aristotle' ungrafted and 'Aristotle' self-grafted controls in this experiment (Table 5).

These results are consistent with those of others regarding susceptibility of the rootstocks to *M. incognita* infestation (Fery

Table 5. Effects of grafting and inoculation with *Meloidogyne incognita* on *M. incognita* J2 isolated from soil and roots, microbivorous (free-living) nematodes isolated from soil and roots, and galling on *Capsicum* rootstocks grafted with 'Aristotle' bell pepper as a scion in experiment 3.

	M. incognita /100 cc soil	Microbivorous /100 cc soil	*M. incognita* /g root	Microbivorous /g root	Gall rate[X]	Root condition[Y]
'Aristotle' ungrafted	174.6 bc[Z]	2297.5 ab	4.62 b	18.68 b	1.60 b[Z]	1.26 bc
'Aristotle' self-grafted	124.7 bc	1712.3 abc	3.71 b	21.16 b	0.84 bc	1.24 bc
'PA-136'	1290.5 a	1288.2 bc	48.40 a	55.72 b	3.64 a	1.60 ab
'Caribbean Red Habanero'	512.6 b	1283.7 bc	9.20 b	144.74 a	3.12 a	1.66 a
'Yolo Wonder'	77.1 bc	1769.0 abc	1.96 b	13.69 b	0.90 bc	1.14 c
'Keystone Resistant Giant'	43.1 bc	1329.0 bc	0.88 b	14.04 b	0.12 c	1.34 abc
'Charleston Hot'	38.6 bc	877.7 c	0.00 b	15.47 b	0.08 c	1.36 abc
'Carolina Wonder'	34.0 bc	1467.4 bc	1.07 b	17.42 b	0.18 c	1.18 c
'Charleston Belle'	31.8 bc	2909.8 a	0.00 b	8.42 b	0.12 c	1.20 c
'Mississippi Nemaheart'	20.4 c	1481.0 bc	0.00 b	14.60 b	0.22 c	1.16 c
'Carolina Cayenne'	0.0 c	1231.5 bc	0.00 b	16.38 b	0.08 c	1.34 abc
LSD (0.05)	490.63	1382.2	10.63	69.28	1.24	2.94

[W]All rootstocks were grafted to 'Aristotle' as the scion cultivar with the exception of 'Aristotle' ungrafted, which was included as a control.
[X]Gall rates based on of Zeck's gall index.
[Y]Root condition rating based on 0 = no discoloration, 4 = completely rotted.
[Z]Means with the same letter are not significantly different.

and Dukes, 1996; Fery *et al.,* 1998; Oka *et al.,* 2004). No apparent incompatibility of the rootstocks to the scion was observed in these experiments and the resulting grafts were secure. It appears that resistance to *M. incognita* is durable and is maintained following grafting of scion varieties possessing the horticultural characteristics important to growers onto the resistant rootstocks. Use of this approach has great potential for nematode management in sustainable high-value crop production systems.

ACKNOWLEDGEMENTS

This research is supported by the CSREES Methyl Bromide Transitions Grant "Use of grafted seedlings for methyl bromide transition in U.S. open-field fresh vegetable production." Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the United States Department of Agriculture. The authors would like to acknowledge Amanda Rinehart, Andrew Bantel, John Mulvaney, and Jackie Markle for their technical assistance, as well as Richard Fery (USDA-ARS, Charleston, SC), and Seminis Seed for supplying seed.

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Received: *7/II/2008*

Recibido:

Accepted for publication: *2/V/2009*

Aceptado para publicación