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Reproduction of *Meloidogyne chitwoodi* on Popcorn Cultivars[1]

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Abstract: Popcorn cultivars were evaluated in field and greenhouse tests for resistance to the Columbia root-knot nematode, *Meloidogyne chitwoodi*, as potential resistant crops in potato rotations. A nematode reproductive factor (Rf) was calculated for each cultivar. Reproductive factor values also were compared on a relative basis as percentages of the Rf on a susceptible field corn standard, Pioneer 3578. Popcorn cultivars W206 and Robust 33–77 consistently supported low population densities of *M. chitwoodi* in repeated tests. However, WOC 9508 had the greatest resistance in any of the field tests, with an Rf value of 0.04. Cultivars with a mean field and greenhouse Rf value less than 50% of the value for Pioneer 3578 were WOC 9508 (8%), WOC 9554 (13%), W206 (15%), WOX 9512 (23%), Robust 33–77 (30%), Robust 20–70 (38%), WOC 9510 (41%), and WOC 9504 (42%). If these cultivars were used in rotation, *M. chitwoodi* population densities at the end of the popcorn season would be between 58% and 92% less than if Pioneer 3578 were grown. In greenhouse tests, WOX 9511, WOX 9528, WOC 9556, and WOX 9531 also had low Rf values (7–46% that of Pioneer 3578), but field testing of these cultivars is needed.
Key words: crop resistance, crop rotation, *Meloidogyne chitwoodi*, nematode, popcorn, root-knot nematode, *Zea everta*.

Columbia root-knot nematode, *Meloidogyne chitwoodi*, decreases the quality of potato tubers. The development of *M. chitwoodi* females in Russet Burbank tubers causes brown spots in the cortex and bumps on the surface, rendering tubers unacceptable for either processing or fresh market sale (Golden et al., 1980; Finley, 1981).

Fumigant nematicides are reported as the most effective chemicals against *M. chitwoodi* (Griffin, 1989; Williams, 1993). Non-fumigants are effective complements to fumigants for reducing population densities below the damage threshold (Pinkerton et al., 1986; Santo et al., 1989). Non-fumigants applied alone, however, have failed to provide acceptable levels of control (Nyczepir et al., 1982; Pinkerton et al., 1986; Santo et al., 1988).

Complementing the use of nematicides in potato production, use of a cover crop (Mojtahedi et al., 1993a, 1993b) or a resistant rotation crop before planting potato could possibly improve control. However, in the Pacific Northwest, susceptibility to *M. chitwoodi* has been observed in the crops commonly rotated with potato, such as wheat, oat, barley, field corn, and sweet corn (Inserra et al., 1985; Santo and O'Bannon, 1981). Alfalfa is resistant to *M. chitwoodi* race 1 but susceptible to race 2 and, therefore, not effective for nematode management if race 2 is present (Griffin, 1986; Pinkerton et al., 1987). O'Bannon et al. (1982) and Ingham (1991) tested many different crops for susceptibility to *M. chitwoodi* and found variation among cultivars of the same crop for several different types of crops. Thus, cultivar selection is an important consideration when choosing a rotation crop.

Although *M. chitwoodi* is not known to reduce corn yields, many corn cultivars support substantial population growth of this nematode (O'Bannon et al., 1982), increasing the risk of nematode damage to a following potato crop. In host tests of potential rotation crops, certain popcorn cultivars were found to be resistant to *M. chitwoodi* (Ingham, 1991). When grown in rotation, these cultivars could reduce population densities before nematicides are applied for control of *M. chitwoodi* in a potato crop. However, the availability of popcorn cultivars changes rapidly as new ones are developed and old ones are abandoned by seed producers. Therefore, information on resis-

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tance to *M. chitwoodi* of new cultivars is needed.

The objectives of this study were to evaluate the resistance of popcorn cultivars to *M. chitwoodi,* and to determine the suitability of popcorn for suppressing nematode population densities prior to a potato crop.

Materials and Methods

The reproduction of *M. chitwoodi* on different popcorn (*Zea everta*) cultivars was evaluated during 1994–96. Those cultivars selected (Table 1) were chosen based on suspected resistance to *M. chitwoodi* in their breeding lines, as indicated by seed companies. Most were tested in the greenhouse and in the field.

Greenhouse Experiments

Two greenhouse experiments included the same cultivars tested in field test 1 (Table 2) plus Robust 85–210. Two more greenhouse experiments included the same cultivars as field test 2 (Table 2), except that Robust 90135 was excluded and WOX 9511, WOX 9528, WOX 9531, and WOC 9556 were added. Wheat cv. Stephens was included in greenhouse experiments 3 and 4 as a positive control (Table 1). Field corn cultivars were included for comparison with popcorn cultivars because field corn is a susceptible crop commonly rotated with potato in the Columbia Basin and has the same growing season as popcorn. Field corn cv. Pioneer 3732 was used as a standard in earlier studies and was included in greenhouse tests 1 and 2 for comparison with Pioneer 3578.

M. chitwoodi race 1 (WAMC1, originally obtained from the Washington State University nematode collection) was maintained on greenhouse cultures of tomato (*Lycopersicon esculentum* cv. Columbian) and wheat (*Triticum aestivum* cv. Stephens). Egg inocula for each greenhouse experiment were obtained from the roots of these plants by extraction with 0.5% sodium hypochlorite (Hussey and Barker, 1973). Popcorn seedlings were germinated in seedling trays, and

TABLE 1. Reproduction of *Meloidogyne chitwoodi* on field corn, wheat, and popcorn cultivars in the greenhouse.

Cultivar	Pf[a]	Rf[b]	Relative Rf[c]
	Test 1		
Field corn			
Pioneer 3578[d]	21,033 b	2.61 cd	100
Pioneer 3732[d]	7,759 cd	0.96 ef	37
Popcorn			
Robust 90477	27,191 b	3.38 c	130
Robust 90135	21,221 b	2.63 cd	101
McHone 910	14,852 c	1.84 d	70
Robust 20–70	4,332 de	0.54 f	21
Robust 33–77	3,309 e	0.41 f	16
	Test 2		
Field corn			
Pioneer 3578	18,167 ab	3.65 ab	100
Pioneer 3732	6,519 cd	1.31 de	36
Popcorn			
W104	29,701 a	5.98 a	164
W108	13,233 bc	2.66 bc	73
W110	9,920 bc	2.00 cd	55
W204	9,620 cd	1.93 cde	53
Robust 85–210	7,995 cd	1.61 cde	44
Robust 30–77	4,673 d	0.94 ef	26
W 206	1,916 e	0.38 f	10
	Test 3		
Wheat cv. Stephens	13,752 b	2.24 b	224
Field corn			
Pioneer 3578	2,455 c	0.40 c	100
Popcorn			
WOC 9506	1,180 cd	0.20 cd	49
WOC 9510	846 cde	0.14 cd	35
WOX 9507	746 cdef	0.12 cd	30
WOC 9503	614 cdef	0.10 cd	25
WOC 9504	526 def	0.08 cd	21
W206	312 f	0.05 cd	13
WOC 9508	295 ef	0.05 d	12
	Test 4		
Wheat cv. Stephens	76,467 a	24.90 a	634
Field corn			
Pioneer 3578	12,066 b	3.93 b	100
Popcorn			
WOX 9511	5,575 c	1.82 c	46
WOX 9528	2,242 d	0.73 d	19
WOX 9512	1,761 de	0.57 d	15
WOC 9554	971 ef	0.32 d	8
WOC 9556	937 ef	0.31 d	8
W206	873 f	0.29 d	7
WOX 9531	864 ef	0.28 d	7

In each test, means within the same column followed by the same letter are not different according to an LSD test ($P \leq 0.05$).

[a] Eggs extracted from root systems 55 days after inoculation. Inoculum levels (eggs/plant): Test 1 = 8,060; Test 2 = 4,970; test 3 = 6,140; test 4 = 3,070.

[b] Reproductive factor (Rf = final egg density/initial eggs inoculated).

[c] Relative Rf represents nematode reproduction on each cultivar as a percentage of the reproduction on Pioneer 3578.

[d] Field corn standards.

TABLE 2. Reproduction of *Meloidogyne chitwoodi* on field corn and popcorn cultivars in the field during 1994 and 1995 at Hermiston, Oregon.

Cultivar	Pi[a]	Pf[b]	Rf[c]	Relative Rf[d]
		Test 1		
Field corn				
Pioneer 3578[e]	1,029	4,344 ab	5.55 a	100
Popcorn				
W108	1,535	4,097 abc	4.86 ab	89
W110	1,081	3,279 abc	4.54 ab	82
Robust 90477	2,522	6,430 a	3.96 ab	73
W104	1,561	4,696 ab	3.95 ab	73
W204	1,273	3,018 cd	3.56 abc	65
McHone 910	2,068	4,225 ab	3.20 abc	58
Robust 90135	2,037	2,643 bc	2.98 abc	54
Robust 20–70	1,278	2,357 bc	2.98 abc	54
Robust 30–77	2,019	2,748 abc	1.57 bc	29
W206	1,207	1,083 d	1.42 c	25
Robust 33–77	1,270	1,136 d	1.23 c	22
		Test 2		
Field corn				
Pioneer 3578	1,565	675 a	1.00 abc	100
Popcorn				
WOC 9503	1,299	496 ab	1.24 a	124
WOC 9506	550	717 a	1.23 ab	123
WOC 9507	1,010	370 abc	1.07 abcd	107
Robust 90135	1,107	347 abc	0.63 bcd	63
WOC 9504	1,066	282 bcd	0.63 bcd	63
Robust 33–77	309	110 bcd	0.53 bcd	53
WOC 9510	425	185 abcd	0.47 bcd	47
WOX 9512	665	71 cde	0.30 bcd	30
W206	623	32 de	0.20 cd	20
WOC 9554	469	80 bcde	0.17 cd	17
WOC 9508	414	13 e	0.04 d	4

In each trial, means within the same column followed by the same letter are not different according to an LSD test ($P \leq 0.05$).
[a] Initial population density (second-stage juveniles/250 g dry soil) at planting, 25 May 1994 (Test 1), and 9 June 1995 (Test 2).
[b] Final population density (second-stage juveniles/250 g dry soil) after harvest, 3 November 1994 (Test 1), and 5 October 1995 (Test 2).
[c] Reproductive factor (Rf = final population density/initial population density).
[d] Relative Rf represents nematode reproduction on each cultivar as a percentage of the reproduction on Pioneer 3578.
[e] Field corn standard.

individual 15-day-old seedlings were transferred to 15.2-cm-diam. pots containing a soil mix of 1:1, fine sandy loam/sand with a pH of 6.5. Popcorn roots received a 7-ml suspension of eggs during transplanting. Plants were inoculated on 3 February and 7 February 1995 in greenhouse tests 1 and 2, respectively, and on 24 January and 7 February 1996 in greenhouse tests 3 and 4, respectively. Each pot in the five replicates of each cultivar was inoculated with 8,060 and 4,970 eggs in greenhouse tests 1 and 2, respectively, and with 6,140 and 3,070 eggs in greenhouse tests 3 and 4, respectively. Pots in each test were placed in a randomized block design on a greenhouse bench and given supplemental lighting (400W halogen bulb for 2 hours in morning and 2 hours in evening) to provide a 12-hour day. A fertilizer solution of $CaNO_3$, $CaHPO_4$, and KCl in a ratio of 9.8:9.5:9.5 was applied every 10 days. Fifty-five days after inoculation, roots were washed and cut into 2- to 4-cm pieces, which were then shaken for 3 minutes in 0.5% sodium hypochlorite. The extracted eggs were collected on a 26-µm-pore sieve and counted.

Field Experiments

Cultivars (Table 2) were grown in soil infested with *M. chitwoodi* race 1 at the Hermiston Agricultural Research and Extension Center, Hermiston, Oregon. The soil was classified as an Atkins fine sandy loam (76%

sand, 17% silt, 7% clay). Soil populations of *M. chitwoodi* had been increased by growing highly susceptible winter wheat cv. Stephens.

Cultivars were planted on 13 May 1994 (field test 1) and 3 June 1995 (field test 2) in 6-m-long single-row plots with a John Deere 71 Flex Planter. Seed spacing was 15 cm, and row spacing was 86 cm. Each cultivar was replicated six times in a randomized block design. A commonly grown cultivar of field corn (Pioneer 3578) was planted as a standard susceptible crop for comparison. Initial nematode population densities (Pi) were determined from each plot on 25 May 1994 (field test 1) and 9 June 1995 (field test 2). Final population densities (Pf) were determined on 3 November 1994 (field test 1) and 5 October 1995 (field test 2) by taking 2.5-cm-diam soil cores to depth of 30 cm next to each of 10 plants per plot. The cores were composited for each plot, and nematodes were extracted from a 250-g subsample by centrifugal flotation (Ingham, 1994, Jenkins, 1964). Soil moisture was determined for each sample before extraction, and the number of *M. chitwoodi* second stage juveniles per 250 g dry soil was calculated.

Data Analysis

A reproductive factor (Oostenbrink, 1966) (Rf = Pf/Pi) was calculated for each replicate in the greenhouse and field tests. A relative Rf also was calculated to express nematode reproduction on popcorn as a percentage of the reproduction on the susceptible field corn cv. Pioneer 3578 in order to standardize Rf values and allow comparisons between different tests.

All count data were transformed to $\log_{10}(x + 1)$ before calculation of Rf values and statistical analysis (SPSS, Chicago, IL). Transformed nematode counts and Rf values were analyzed with ANOVA. Significant ($P \leq 0.05$) differences between means were partitioned with a protected least significant difference (LSD) procedure.

Results and Discussion

Nineteen popcorn cultivars were tested in both the greenhouse and field. In field tests, cultivars supporting lower ($P \leq 0.05$) *M. chitwoodi* reproduction than the field corn standard, Pioneer 3578, were Robust 30–77, W206, Robust 33–77, and WOC 9508 (Table 2). They also had lower ($P \leq 0.05$) Rf values than Pioneer 3578 in the greenhouse (Table 1). Rf values for WOX 9512 and WOC 9554 were less than the Rf for FC 3578 in the greenhouse, but not in the field (Tables 1,2).

The means of the relative Rf values were averaged over field and greenhouse tests to establish relative rankings of the cultivars. Those with mean field and greenhouse Rf values less than 50% of the Rf value of Pioneer 3578 were WOC 9508 (8%), WOC 9554 (13%), W206 (15%), WOX 9512 (23%), Robust 33–77 (30%), Robust 20–70 (38%), WOC 9510 (41%), and WOC 9504 (42%). If these popcorns were used in rotation, *M. chitwoodi* population densities at the end of the popcorn season would be between 58% and 92% less than if Pioneer 3578 were grown.

W206, tested five times, and Robust 33–77, tested three times, had the most consistent resistance to *M. chitwoodi* in popcorn (Tables 1,2). WOC 9508 also exhibited strong resistance to *M. chitwoodi*, with an Rf value of 0.04 (Table 2) in field test 2. Based on field tests, if WOC 9508 is planted instead of Pioneer 3578 in rotation before potato, the pre-potato count should give 96% fewer *M. chitwoodi*, thus significantly reducing the threat to the potato crop.

Cultivars that were tested only in the greenhouse, but which demonstrated much lower relative Rf values than the field corn standard, Pioneer 3578, were WOC 9531 (7%), WOC 9556 (8%), WOX 9528 (19%), and WOX 9511 (46%) (Table 1). However, these popcorns should be tested in the field before being recommended as resistant alternatives to Pioneer 3578.

Popcorn does not suppress *M. chitwoodi* population densities as well as some other summer crops (O'Bannon et al., 1982; Ingham, 1996), but it may be preferred by corn growers over a crop they have not grown and that may require additional equipment. The statistical differences in resistance among popcorn cultivars may be relevant only to the potato grower if the overall control practices for *M. chitwoodi* are affected. The economic threshold for *M. chitwoodi* infection in potatoes is <1 second-stage juvenile/250 g dry soil (Santo et al., 1981). Less expensive non-fumigant nematicides may be used if they can reduce nematode densities below this threshold level following a resistant rotation crop. Thus, cultivar selection is important only if some cultivars reduce population densities adequately. Population densities not suppressed adequately by resistant rotation crops or non-fumigants must be reduced through soil fumigation (Santo et al., 1988, 1989).

There is considerable variability in resistance and susceptibility among popcorn cultivars, and there may be variability in field corn cultivars as well, since Rf values differed ($P \leq 0.05$) between Pioneer 3732 and Pioneer 3578 (Table 1). New cultivars of both types of corn are constantly being released. For example, potentially resistant cultivars may be developed from parentage similar to that of popcorn cultivars W206 or Robust 33–77. Continued testing of new cultivars will be needed to advise growers of the relative resistance or susceptibility of new releases and their potential usefulness in management of *M. chitwoodi* in potato.

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