Carrot Breeding to Develop and Introduce Improved Cultivars for California Producers

Annual Research Report to California Fresh Carrot Advisory Board
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Growers, shippers, seed producers

A. Field Trial of USDA Breeding Stocks and Hybrids for California

1. 1306 USDA experimental breeding entries (inbreds, new crosses, segregating populations, unadapted and undomesticated material) were grown at the Desert Research and Extension Center (DREC). Yield components evaluated include root length, shape, sprangles (forking, presumably due to soil compaction, perhaps pythium), smoothness, tip shape, and length, uniformity, premature bolting, vigor, earliness, and powdery mildew. Quality components include color, smoothness, flavor (sweetness and harshness), texture, and nutritional value (carotene and anthocyanin pigment levels). There were 114 advanced baby, 28 cello, 82 novel color inbreds, and 655 new diverse base populations (for nematode resistance, length, flavor, and color) included in the trial. A summary of the characteristics of selected recent unreleased USDA carrot inbreds developed and being used in the USDA program is presented in Table 1.

2. 43 cello and 76 baby USDA and seed company hybrids were grown at DREC and evaluated visually by carrot growers, seed producers, and researchers and each given a composite rating (Table 2). New USDA hybrids performed well in the trials with 10 baby, 4 cello entries in the top 20, and 2 novel entries in the top 10 of their respective classes. This was the sixth year that we included nematode resistant inbreds as components to cello and cut & peel hybrids among USDA entries, and among the 15 top cello hybrids from the USDA program, 13 had an inbred parent derived from nematode resistant backgrounds and 7 had both resistant parents. This was our thirteenth year to perform a specialty carrot trial that included 17 entries with unusual color or shape. Flavor evaluation was also performed for all entries.

3. Forty-seven inbreds or populations are being tested further by seed companies (listed in Table 1). Fourteen of these are *Meloidogyne javanica* and/or *M. incognita* resistant inbreds included in evaluations in infected fields reported below.

4. Joe Nunez also performed field trials including USDA experimental hybrids and populations. Please refer to his report for those results.

B. Breeding for Nematode-Resistant Carrots

Incorporating Resistance from 'Brasilia' Germplasm

Studies we have published demonstrate that the first nematode resistance gene to be extensively evaluated in carrot is *Mj-1* derived from 'Brasilia 1252'. *Mj-1* is on chromosome 8 and it controls the inheritance of the resistance to *Meloidogyne javanica* and also imparts partial resistance to *M. incognita.* We have also observed *Meloidogyne javanica* and *M. incognita* resistance from another strain of Brasilia ("Brasilia 1091'), and more recently from a similar South American cultivar – 'Uberlandia'. The *M. incognita* resistance from both 'Brasilia' strains is controlled, in part, by the *Mj-1* genetic region.

In addition to *Mj-1*, a gene on chromosome 1 of South American carrots also contributes to *M. incognita* resistance (Parsons et al. Molec. Br.35:114, 2015). In the last year we also discovered additional MiR QTLs on chromosomes 4 and 6 in 'Brasilia 1252' derivatives. Work is underway to determine the relative value of these genes in developing strong and durable resistance for California production. The importance of these genetic regions to developing *M. incognita* – resistant carrots has motivated our development of molecular markers to assist breeders in incorporating this resistance in new breeding stocks for California. With the sequence of the carrot genome in hand, numerous markers are now available to facilitate incorporation of multiple nematode resistance genes, and candidate genes are being identified. To accompany the release of 'Brasilia'-derived germplasm to the seed industry, we have published information on markers (Parsons et al., 2015).

At the South Coast Station 700 diverse seed sources were grown by Dr. Roberts on *Meloidogyne incognita* and *Meloidogyne javanica* infested fields including adjacent susceptible check plots throughout both fields. Harvest was in October and included a field day with industry invited to attend. Inbreds derived from resistance sources mentioned above were resistant and sub-populations of selected roots were sent to Madison for seed increase. These included intercrosses of all sources of resistance with each other, and with good-flavored and long carrots adapted for production in California are at F_4 to F_{10} generations. Several selections form 'Brasilia' and other genetic backgrounds have excellent resistance (both *M. javanica* and *M. incognita* resistance scores of 0-1, see Dr. Roberts' report) and suitable length, smoothness, and flavor. Several of these same breeding stocks

were also grown in the DREC trials, where they had length, smoothness, color, and flavor suitable for California production. These inbreds are derived from the *Mj-1* single source of resistance or combinations of *Mj-1* and the chromosome 1 and 8 resistance genes backcrossed into an unrelated, dark orange, good flavor, long, smooth inbred. This confirms that strong nematode resistance can be bred into diverse genetic backgrounds adapted for production in California without compromising resistance. Seed of five inbreds derived from 'Brasilia 1252' is released and has been distributed to all of the major seed companies breeding carrots for the North American market, as well as to other carrot researchers.

We invited the carrot seed industry to submit entries for evaluation of nematode resistance, in the South Coast Station infested fields. Multiple entries were received from 4 seed companies and evaluated. The full range of resistance ratings was observed, and resistance scores of 0 and/or 1 were observed in entries from several seed companies.

C. Establishing Carrot Populations with Nematode Resistance from Other Germplasm Sources

Additional sources of resistance beyond 'Brasilia 1252' (MJ) and 'Brasilia 1091' (1091) noted above have been derived from Syria ('Homs' HM), China ('Ping Ding' PD), Australia ('Western Red' WR), Europe ('Scarlet Fancy' × 'Favourite', SFF; and 'Nantes Fancy', NF) and are being genetically mapped and characterized. A second major gene, *Mj-2*, accounts for part of the 'Ping Ding' resistance, and it is on the same chromosome as *Mj-1*, but 30- 35 cM away (Ali et al. J. Hered. 105:288, 2014). Field evaluation of resistance derived from all these sources was tested at both the South Coast Station and in the greenhouses by Dr. Roberts. Like MJ derivatives, these resistance sources also had variable levels of resistance among inbreds being developed from them, with inbred scores ranging from roughly 1 to 5. Scores of 2 and above reduce marketable yield significantly. MJ, BR, SFF, HM and PD selections had high levels of resistance, and all sources had individual roots with scores of 1 or less. Resistance from HM and SFF in particular has been strong, and this was observed again in the last year. Homs has nematode resistance genes at or near the *Mj-1* BR resistance gene on chromosome 8, but also has additional resistance genes on chromosomes 1, 2 (2 genes) and 9. SFF has a resistance gene at or near the *Mj-1* BR resistance gene on chromosome 8, and also has an additional resistance gene on chromosome 4. In addition to the *Mj-1* resistance on chromosome 8, the chromosome 9 resistance from HM is particularly strong, as is the chromosome 4 resistance from SFF. Since we discovered a major resistance QTL on chromosome 4 in 'Brasilia 1252' this year, another upcoming effort will address the efficacy of resistance of the chromosome 4 gene from 'Brasilia 1252' relative to that from SFF. The discovery of resistance genes on chromosomes 1, 2, and 8 from unrelated genetic sources may indicate multiple alleles for the same genes (since they map to similar regions of these three chromosomes), or perhaps reflect genes linked but not allelic, since resistance

genes are often clustered in other plants. Breeding stock combining these diverse resistance genes are being assembled to address these questions. In evaluating the carrot genome sequence we found that carrot has over 600 putative resistance genes (potentially imparting resistance to numerous pathogens, not just nematodes) and several are in a cluster at or near the *Mj-1* BR resistance gene on chromosome 8 (Iorizzo et al., Nature Genetics 48:657, 2016), as well as other QTL we have mapped. These different genes apparently have a cumulative effect in strengthening resistance, to complement those for *Mj-1*, but it is not yet clear whether resistance genes from all QTL need to be combined to provide the strongest resistance, or whether certain alleles or closely linked genes from one genetic source (e.g. *Mj-1* on chromosome 8 from 'Brasilia') are stronger than those from an unrelated source (e.g. the SFF and HM resistance genes also on chromosome 8, and mapped closely to *Mj-1*). The development of breeding stocks to assemble new combinations of genes and alleles will help clarify our understanding of how these multiple genes can best be combined to confer durable nematode resistance.

Segregating populations incorporating combinations of resistance, or intercrossing resistance into long, high color, good flavor susceptible backgrounds have been established and advanced in the breeding program, and most combinations of resistance are being tested (Table 3). We have produced seed of several F_2 through F_7 populations that combine multiple sources of resistance. Inheritance studies underway provide basic scientific information and the basis for development of molecular markers which seed companies and our program can use to incorporate resistance into carrot germplasm backgrounds adapted for California. Seed was sent to Dr. Roberts for testing plants grown in greenhouses and inoculated with nematode eggs. Resistant and susceptible roots were selected and are used for seed production in Wisconsin. Resistance data gathered to date for segregating populations is provided in Dr. Roberts' report.

Of the crosses within and between these multiple sources of resistance, populations with a high incidence of strong *Meloidogyne incognita* resistance (MiR) were observed. Average scores were low (0-1) in several early generation populations (see trial data for F_3 and F_4 families in the first 155 plots in Dr. Roberts' report) from field trials at the South Coast Station, combining MJ with HM, NF with HM, MJ with PD, and HM with SFF, suggesting that most of the derivative plants from these populations would be expected to have a relatively high level of nematode resistance. Currently greenhouse seed production is underway in the greenhouse for selected roots from the South Coast trials with MiR scores of 2.0 or less. These materials will be used to determine if multigenic resistance can be widely incorporated into carrots for California production with limited use of nematicides.

Beyond the seven primary sources of nematode resistance genes we have studied to date (Table 3), seed samples of F_4, F_5, and F_6 derivatives were generated in the last year to be evaluated for resistance segregation patterns in new promising

sources of resistance from cultivated carrots in the South American (open-pollinated cultivar 'Uberlandia') noted above. 'Uberlandia' derivatives also had resistance scores in the range of 2-3 as well as robust overall growth. Intercrosses with these derivatives will be evaluated to determine if resistance is due to the same genes already identified, or whether additional nematode resistance genes occur in carrots. Additional new sources of resistance have been identified in diverse open-pollinated cultivars and land races from Africa, Asia, and Europe, and promising new gene sources are being intercrossed with characterized resistance sources, and with susceptible carrots, to expand the numbers and diversity of resistance genes available for carrot breeders, and to develop more robust carrot breeding strategies for nematode resistance.

Greenhouse evaluation of carrots proven to have strong Mi resistance in previous collaborative research were further evaluated for resistance response when exposed to several new root knot nematode strains and species by Dr. Roberts (see his report) and selected roots were sent to Wisconsin. Seed production from 2016 was evaluated in 2017 and more seed production and molecular marker evaluation is underway to generate seed, including self-pollinations and crosses to susceptible carrots for future progeny analysis and genetic analysis.

D. Identifying Genetic Sources of Cavity Spot Resistance

Based upon the wide range of disease response by Dr. McDonald in previous evaluations, crosses were made last year between resistant and susceptible inbred plants, and also among plants from resistant seed sources grown in our DREC trials. Several cavity spot resistant (C1131, F5367, Nb6526) and susceptible (Nb2205, F5494) inbred parental stocks, and hybrids of those parents with F_1 seed parents with intermediate resistance were tested in 2017 to advance studies of the inheritance of cavity spot resistance. Hybrids generally were more resistant or susceptible than average, depending on whether the pollen parent was resistant or susceptible. Detailed results of those evaluations are found in Dr. McDonald's report. Carrot seed from the USDA breeding program was also included in a cavity spot trial by Dr. Nunez. A range of diverse genotypes was evaluated, and the pattern of disease attack among diverse genetic stocks was fairly consistent with results that have been observed Dr. McDonald's trials, although there were exceptions. Additional potential new sources of resistance were also tested.

Roots of resistant plants Dr. McDonald's evaluations were shipped to Wisconsin and are being used in our winter 2017-2018 greenhouse seed production nursery to develop seed stocks for future genetic analysis of disease resistance and advance resistant stocks in our breeding program.

E. Evaluation of Carrot Germplasm and Advanced Selections for Alternaria Leaf Blight Resistance

Field evaluation of *Alternaria dauci* resistance was performed in Wisconsin. Resistance was observed in 704 land race carrots, and in derivatives of several wild carrots crossed with modern cultivated inbreds. Several hybrids, backcrosses and testcrosses were made among these items for testing. Segregating populations are being tested for genetic studies discussed above. Individual plant selection is not very effective for Alternaria resistance, so resistance evaluations are made on progeny families of selected individuals. Molecular fingerprints are being assayed in resistant breeding stocks to develop markers to track resistance. New genetic sources of resistance from 17 open-pollinated cultivars or land races in the USDA Plant Introduction germplasm collection were identified and crosses were made between these genetic stocks and with inbreds adapted for production in California. Hybrid combinations are being developed for additional field testing.

F. Seed Production and Laboratory Analysis

1. Roots from California trials were sent to Wisconsin for seed production. Seed yields were average in our 94 cages and 705 breeding plot isolations in the summer, and average to above average in 1315 greenhouse cages in the winter greenhouse. These roots were used to produce seed of 44 new experimental hybrids, and 208 new experimental breeding stocks for current and future testing.

2. Detailed flavor and texture evaluation was made on 341 populations and carotene was quantified in 23 of them to estimate nutritional value (see Table 1). Seed was sent to cooperators for testing. Of particular interest are nutritional properties and flavor in populations with elite nematode resistance. A range in color and nutritional value has been confirmed in these materials, indicating that nutritional quality or flavor will not need to be sacrificed to incorporate nematode resistance.

3. Roots selected for nematode resistance from the field trials and from Dr. Roberts' greenhouse testing program were sent to Wisconsin for seed production as mentioned above. Seed production was above average. We produced 4 new F_1 intercrosses combining unrelated sources of resistance, 11 F_2 populations segregating for multiple sources of resistance in California-adapted background, and 107 inbreds to be tested for MI resistance. Large-scale seed production by industry collaborators of selected items will supplement seed supplies. These will be very valuable in pursuing future evaluations of nematode resistance genetics and development of breeding stocks.

4. Roots selected for cavity spot resistance from the field trials of Dr. McDonald's testing program were sent to Wisconsin for seed production as mentioned above. Seed production was above average. We produced 3 new F_1 intercrosses

combining unrelated sources of resistance and generated 6 F_2 populations segregating for resistance in California-adapted background. Seventeen F_3 families derived from cavity-spot resistant parents were also generated, and horticultural performance evaluated at DREC. Seed was produced from selected roots which will be valuable in future cavity spot resistance genetics and breeding.

G. Carrot Molecular Genetic Markers

Markers developed in our previous research are being used to select for nematode resistance in segregating populations from diverse backgrounds and to identify candidate genes. In addition to the fine mapping for new nematode resistance genes in a 'Brasilia 1252' – derived population that provided evidence for additional resistance QTLs on chromosomes 4 and 6 noted above, we initiated an effort to pursue an association analysis of multiple sources of nematode resistance in breeding stocks generated in previous years of this project. Using the carrot genome sequence, we are utilizing data from this effort to develop molecular markers linked to additional major resistance QTL. Molecular markers associated with genes for alternaria resistance, early flowering, sugar and pigment content, root color, and components of carrot flavor are also being identified. Marker information is being shared with seed companies to facilitate their selection programs.

Table 1. Selected USDA Carrot Breeding Lines

Inbred	Source	Color	Smooth-ness	Flavor	Length cm	Industry Testing	Tip	Use	Other Traits	Remarks
Orange Cello, Cut & Peel Inbreds and Breeding stocks										
L0567	FN2-9 × 2302	4	3.5	3.5	27	x		CP		Long parent
1131	Long Red surrey × HCM	5	3	2	16	x	Taper	Cavity Spot Res.		Best Cavity Spot Resistance
1137	Good Flavor Mass	3	4	5	13	x	Intermediate	Cavity Spot Res.		Good cello parent
1138	HTDS/HRS	3	3	3	14	x	Blunt +	Cello		Good cello pollinator
Nb1175	8483 × 9256	4		3	28	x		Cello	MjR, MiR	Strong nematode resistance S.C.'10; High rank hyb. '14 DREC
Nb1391	8483 × 9256	4		4	27	x		Nematode Res.	MjR, MiR	Strong nematode resistance Kearney 2013, '16
1401	FN2-9 × 2302	4		4	23	x		Cello		Cello parent
L1408	FN2-9 × 2302	4		4	28	x		CP		High Rank Hybrid 2013, '16 DREC
2126	2566 × 3475	3	4	4	15	x	Blunt	CP, Cello	Sprangles =5	Good Hybrid Seed Parent
2144	3180 × 6274	4	4	3	20	x	Blunt	Cavity Spot Res.	Sprangles =5	Good Hybrid Seed Parent
Nb2155	BR × 6274	4		4	22			Cello	MjR, MiR	Strong nematode resistance S.C.'14, Kearney '16
Nb2159	BR × 6274	3		3	22	x		Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2015
Npw 2191	PD × WR	3		3	18	x		Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2016
Nb2195	BR × 6274	3		4	24			Nematode Res.	MjR, MiR	Strong nematode resistance S.C.'14
Nb2205	BR × 6274	4		4	23	x		Nematode Res.	MjR, MiR	Strong nematode resistance Kearney'13, S.C.'14
2226	HTDS/LRS	4		3	25	x		Cavity Spot Res.		Cello parent
L2301	FN2-9 × 9304	4		4	29			CP		High rank hybrid 2013, '15 DREC
Nbh2306	HM × (B × 6)	4	5	4	24			CP, Nematode Re	MjR, MiR	Strong nematode resistance Kearney'13, '16; S.C.'14
2327	5280 × HCM	5		3	27	x	Blunt	CP, Cello		High rank hybrid 2014, '15 DREC
L2575	FN2-9 × 2302	4		4	34	x		CP		High rank hybrid 2012, '13, '16, 17 DREC

1 = Worst, 5 = Best; CP = Cut and Peel type; BR = Brasilia; MjR = M. javanica resistance, MiR = M.incognita resistance; S.C.= South Coast; DREC = Desert Res. Ext. Center

Nb, Nh, Np, Ns, Nw = nematode resistance gene sources 'Brasilia', 'Homs', 'Ping Ding', 'SFF', 'Western Red'

Table 1 (cont.). Selected USDA Carrot Breeding Lines

Inbred	Source	Color	Smooth-ness	Flavor	Length cm	Industry Testing	Tip	Use	Other Traits	Remarks
Orange Cello, Cut & Peel Inbreds and Breeding stocks — continued										
L2577	FN2-9 × 2302	4		4	29	x		CP		High rank hybrid 2013, 17 DREC
3035	2126 × 2144	4	4	4.5	15	x	Intermediate	CP, Cello		Good Combining Ability, High rank hybrid 2015 DREC
Nb3271	BR × 6274	3		4	21	x		Nematode Res.		Strong nematode resistance, Kearney 2015
Nb3284	Nb8483 × 9256	4		4	24			Nematode Res.		Strong nematode resistance, Kearney 2014, '16
F3513	EFM	3		4.5	17	x		Cello flavor		Good flavor cello
L4622	FN2-9 × 2302	4		4	27			CP		High rank hybrid 2014, '15 DREC
C5133	(FN2-9 × 9304) × FS	4.5	3.5	3.5	19	x		High color		Dark orange parent
Nb5192	BR × 6274	4	4.5	4.5	20	x		Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2014, '16
F5367	EFM	3		4	17	x		Cavity Spot Res.		Cello pollinator
L6191	2566 × FN2-9	4	3.5	4+	24		Intermediate	Cello		Long ,Flavor Select
7241	8532 × FN2-9	3	4+	3	21	x	Intermediate	Cello	Blck Crwn =R	Good Combining Ability
L7550	FN2-9 × 9304	4	3.5	4	29	x	Blunt	CP		Long Flavor Select, High rank hybrid 2015, '16 DREC
7808	HTDS/HRS	3		3	19	x		Cello		Flavor Select, High rank hybrid 2015 DREC
Nh8502	Homs	3		3	15	x		Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2016
Nb8529	BR × 6274	3.5		4	18		Intermediate	Nematode Res.		Strong nematode resistance
Nb9324	8503 × Long	3		4	23	x		CP, Cello	MjR, MiR	S.C.'14 Mi and Mj =0 or 1
L9785	FN2-9 × 2302	4		4	30	x	Blunt	CP		High rank hybrid 2009, '13, '15 DREC
L9786	FN2-9 × 2302	4		4	31			CP		High rank hybrid 2015, '16 DREC
L9788	FN2-9 × 2302	4		4	29		Blunt	CP		High rank hybrid 2013, '15 DREC
L9791	FN2-9 × 2302	4		4	24	x	Blunt	CP		High rank hybrid 2009 DREC

1 = Worst, 5 = Best; CP = Cut and Peel type; BR = Brasilia; MjR = M. javanica resistance, MiR = M.incognita resistance; S.C.= South Coast; DREC = Desert Res. Ext. Center

Nb, Nh, Np, Ns, Nw = nematode resistance gene sources 'Brasilia', 'Homs', 'Ping Ding', 'SFF', 'Western Red'

Table 1 (cont.). Selected USDA Carrot Breeding Lines

Inbred	Source	Color	Smooth-ness	Flavor	Length cm	Industry Testing	Tip	Use	Other Traits	Remarks
Novel Colored Breeding Stocks and Gene Sources										
P0114	Red × 7262			4		x	Blunt	Specialty		Purple
R0148	PI 432903			3		x	Blunt	Specialty	Nantes	Red Flavor Select, High rank entry 2015 DREC
P0252	Homs			3		x		Nematode Res.	MjR, MiR	Purple Yellow; Strong nematode resistance Kearney'13
P1129	9304 × PI			4		x		Specialty		Purple Orange; Flavor Select
Y1246	(2566 × FN2-9) × white			4		x		Specialty		Yellow; Flavor Select
W2383	BCVTHT × Wwortel			5		x		Specialty		White
Y3429	JOD × W. Belgian			4		x		Specialty		Dark Yellow, Flavor Select
R4294	Red × 7262			4		x		Specialty		Red, Flavor Select
Y4310	JOD × W. Belgian			4				Specialty Cello		Yellow
R5646	Red × 7262			3		x		Specialty		Red, Flavor Select
P6220	Trksh × 7262			4		x	Taper	Specialty		Purple, Flavor Select
PR6245	(7262 × Trksh) × Flavor			3.5		x	Blunt	Specialty		Purple Red
PR6318	7262 × PI 432903			3.5			Intermediate	Specialty		Purple Red
P6360	(Trksh × 7262) × Best Flavor			4		x		Specialty		Purple, High rank entry 2015 DREC
P6423	PD × Pi132601			4		x		Specialty		Purple
R6636	(432906PRC × 319858,432903) × FS			4		x		Specialty		Red
R6637	432906PRC × 319858JP			4.5		x	Blunt	Specialty	Nantes	Red
R8201	PI 432903			4		x		Specialty		Red; High rank entry 2013, '14 DREC
Y8519	Trksh × 7262			3		x	Intermediate	Specialty		Yellow Imperator

1 = Worst, 5 = Best; CP = Cut and Peel type; BR = Brasilia; MjR = M. javanica resistance, MiR = M.incognita resistance; S.C.= South Coast; DREC = Desert Res. Ext. Center

Nb, Nh, Np, Ns, Nw = nematode resistance gene sources 'Brasilia', 'Homs', 'Ping Ding', 'SFF', 'Western Red'

Table 2. USDA Carrot Trial Results, DREC 2017

USDA California Carrot Trials 2017

Entry	Pedigree or Name	Source	Number of Judges Placing in Class 1	2	3	4	5	Mean[1]	Rank	Flavor[2] H	S
Entries Listed by Field Number											
C701	Maverick	Nunhems	1	1	8.5	9.5	5	3.66		4	4
C702	PV5135	Pop Vriend	2	7.5	7.5	13	3	3.23	13	4	4
C703	Nb2159A x Nb6526B	661–2		4	9.5	14	5.5	3.64	3	4	4
C704	((L1406 x L1401) x L4168) x Nb6167B☆	642–5	8	15	8	2		2.12	37	3.5	4
C705	CR2289	Seminis	1	8	18	6		2.88	21	4	4
C706	(SC x L2577) x Nb6167B ☆	642–2	8	18	5	2		2.03	39	4	4
C707	(6366 x 2226) x 5280	154-7	1	3	10	16.5	2.5	3.50	6	4	4
C708	KXPC-403	Integra	1	8	17	4	3	3.00	20	3.5	4
C709	SV4128DL	Seminis		4	8	18	3	3.61	4	4	4
C710	SV2384DL	Seminis		2	8.5	14.5	8	3.86	2	4	4
C711	(6366 x 5238) x 7254	752–6		5	15.5	10.5	2	3.29	12	4	4
C712	KXPC-020	Integra		19.5	11.5	2		2.47	31	4.5	4
C713	Maverick	Nunhems		7	16	10		3.09	18	4	4
C714	FCR 16581	Sakata		3	10	18	2	3.58	5	4	4
C715	Nb4002A x Nb6526B ☆☆	661–4		13	15	5		2.76	22	4	44
C716	Bull Dog	Nunhems	1	1	8.5	12.5	10	3.89	1	4	4
C717	FCR 12073	Sakata		12	17	4		2.76	23	4	4
C718	(8483 x 42156) x 1386 ☆	512–2	7	15	8	3		2.21	35	4	4
C719	(4001 x 6526) x 9324/4216	576–10	16	13	4			1.64	41	3	3.5
C720	FCR 12070	Sakata	1	15.5	15.5	1		2.50	30	4	4
C721	PV5059	Pop Vriend	2	18	10	3		2.42	33	4	4
C722	PV5103	Pop Vriend	5	18	9	1		2.18	36	3.5	4
C723	FCR 16560	Sakata		4	14	14	1	3.36	10	4	4
C724	Nb2205A x Nb6526B ☆☆	661–3	1	13	18	1		2.58	26	3.5	4
C725	KXPC-404	Integra	1	10.5	19.5	2		2.68	24	4	4
C726	Trooper	Nunhems	2	13	15	3		2.58	27	4	4
C727	(5280 x 6366) x 8233	031-11	17	12	2			1.52	42	2.5	3.5
C728	(6366 x 2226) x 8524	176-6	4	12	13	4		2.52	29	2.5	3.5
C729	(6333 x 8483) x 2126	145-3	3	16	11	2	1	2.45	32	3	3
C730	(SC x 39999) x 9324/4216	576–6	7	18	5.5	2.5		2.11	38	4	4.5
C731	PV5145	Pop Vriend		7	10.5	11.5	4	3.38	9	4	4
C732	Choctaw	Nunhems	1	4	11	15	2	3.39	7	4	4
C733	PV5196	Pop Vriend	1	6	11.5	9.5	5	3.35	11	4	4
C734	(9785 x 0567) x 1386	512–9	4	10.5	13	5.5		2.61	25	4	4
C735	SV2214DL	Seminis	1	4.5	16.5	9	2	3.20	15	4	4
C736	((Nb1393 x L0569) x L4168) x Nb6167B	642–4	11	17.5	3.5	1		1.83	40	2.5	4
C737	Sun 255	Nunhems	1	6	16	9	1	3.09	19	4	4
C738	NUN 85021	Nunhems		5.5	15	6.5	6	3.39	8	4	4
C739	PV5041	Pop Vriend	2	4	13	13	1	3.21	14	4	4.5
C740	FCR 12089	Sakata	1	5.5	16	9.5	1	3.12	17	4	4
C741	(6333 x 8233) x 6526	162-5	1	4	18	9	1	3.15	16	4	4
C742	Rebel	Nunhems	4	13	10	6		2.55	28	4	4
C743	(SC x L4168) x Nb6167B ☆	642–3	6	18	4	5		2.24	34	4	4

[1] Mean based on average of judges: 1 = unacceptable, 2 = poor, 3 = fair, 4 = good, 5 = excellent.

[2] Flavor (1 judge): H = Harshness: 1=Very harsh, 5=Very mild; S = Sweetness: 1=Not sweet, 5=Very sweet

Each ☆ indicates that one parent is a nematode resistant line

Table 2 (cont.). USDA Carrot Trial Results, DREC 2017

USDA California Carrot Trials 2017

Entry	Pedigree or Name	Source	Number of Judges Placing in Class 1	2	3	4	5	Mean[1]	Rank	Flavor[2] H	S
Baby Cut & Peel Trial											
B701	UpperCut	Nunhems			9.5	7.5	5	3.80		4	4
B702	Imperial Cuts	Integra	1	5	8	6	2	3.14		4	4
B703	Propeel	Seminis			4.5	11.5	6	4.07		4	4
B704	(SC x L4168) x L2577B	619–2		1	9	19	3	3.75	4	4	4
B705	SV2765DC	Seminis		1	5.5	16	10.5	4.09	1	4	4
B706	(SC x L4168) x L2577B	619–3	14	12	6	1		1.82	69	4	4
B707	FCR15514	Sakata		7	7.5	10.5	8	3.59	8	4	4
B708	SVDC1978	Seminis			6	19	8	4.06	2	4	4
B709	(Nb1393A x L0567B) x L2577B	619–4	4	15	11.5	1.5	1	2.41	51	4	4
B710	PS1441	Seminis		3	10.5	16.5	3	3.59	9	4	4.5
B711	L1408A x L9785B	671–3	1	5	19	5	3	3.12	20	3.5	4
B712	(SC x 9788) x 4622	363–3		2	13.5	13.5	4	3.59	10	4	4
B713	(9253 x 7551) x 9785	475–5	1	19	11	2		2.42	50	4	4
B714	Propeel	Seminis	1	3	18	11		3.18	18	4	3.5
B715	NUN 85933	Nunhems		4	14	14	1	3.36	13	4	4
B716	(L9785A x L0567B) x L2577B	619–5	7	16	5	4	1	2.27	55	4	3.5
B717	L9793A x L2575B	617–2	3	6.5	17.5	5	1	2.83	30	4	4
B718	Starr	Integra	1	11.5	15.5	5		2.74	33	3.5	4
B719	NUN 85931	Nunhems	1	3.5	16.5	12		3.20	17	4	4
B720	(9253 x 7551) x 6191	491–3		3	7.5	15.5	7	3.80	3	4	4
B721	(9253 x 9788) x 9785	286–7	1	2	18	11	1	3.27	15	4	4
B722	(7550 x 2327) x 9786	476–5	2	17.5	10.5	3		2.44	49	4	4
B723	PV5199	Pop Vriend	2	12	16	3		2.61	39	4	3.5
B724	KXPC-516	Integra		16	15	2		2.58	41	4	4
B725	(7551 x 1131) x 9788	477–2	5	17.5	8.5	2		2.23	57	4	4
B726	Skybar	Integra	7	17	8	1		2.09	60	4.5	4
B727	FCR 15511	Sakata	1	6	15.5	10.5		3.08	22	4	4
B728	(9253 x 7551) x 6191	490–4	13	16	2.5	1.5		1.77	70	4	4
B729	CrispyCut	Nunhems		4	18	9	2	3.27	16	4	4
B730	(L1406A x L0567B) x L2574B	615–4	10	16	5	2		1.97	64	4	4
B731	KXPC-060	Integra	2	17.5	11.5	2		2.41	52	4	4
B732	(L7550A x L1408B) x L9786B	673–4	5	9.5	11.5	7		2.62	37	3.5	4
B733	CR1706	Seminis	3	11	12	6	1	2.73	35	4.5	4
B734	Imperial Cuts	Integra	2	6	17	8		2.94	27	4.5	4
B735	L1408A x L9786B	673–3		7	18	6	2	3.09	21	4	4
B736	(7553 x 2327) x 4623	362–3	3.5	11	14.5	4		2.58	42	4	4
B737	L2304A x Nb3271B ☆	621–5	6.5	19	6.5	1		2.06	63	2.5	3.5
B738	CandySnax	Nunhems	2.5	12.5	14	3	1	2.62	38	4	4.5
B739	(SC x L2577) x L9786B	673–5	7	14.5	10.5	1		2.17	58	4	4
B740	(L7550A x L2574B) x L9793B	676–4	1	4	11.5	13.5	3	3.41	12	4	4
B741	(L7550A x L1408B) x L2577B	620–4		4.5	14	13	1.5	3.35	14	2.5	4
B742	FCR 15469	Sakata		9	14	9	1	3.06	23	3.5	4
B743	PV5183	Pop Vriend		17	13	3		2.58	43	4	4
B744	(9253 x 7551) x 6191	491–4	1	11	10.5	8.5	2	2.98	25	4	4
B745	(SC x 05692)	503–10	3	12.5	14.5	3		2.53	45	4	3.5
B746	(9253 x 7551) x 6190	490–3	1	13	17	2		2.61	40	4	4
B747	(9253 x 7551) x 2576	425–4		8	18.5	6.5		2.95	26	4	4
B748	(L9785A x L2576B) x 2575B	617–5		10	16	7		2.91	28	3.5	2.5

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Table 2 (cont.). USDA Carrot Trial Results, DREC 2017

USDA California Carrot Trials 2017

Entry	Pedigree or Name	Source	Number of Judges Placing in Class 1	2	3	4	5	Mean[1]	Rank	Flavor[2] H	S
Baby Cut & Peel Trial — Continued											
B749	SlenderCut	Nunhems		8.5	15.5	8	1	3.05	24	4	4
B750	(L9793A x L2574B	615–2	1	8.5	11.5	9	3	3.14	19	4	4
B751	(L1406A x L0567B) x L2575B	617–4		2	12	15	4	3.64	6	3.5	4
B752	(SC x L14082) x L2577B	620–3		3	12.5	13.5	4	3.56	11	4	4
B753	(SC x L0567B) x L2574B	615–3	1	22	10			2.27	56	4	4
B754	UpperCut	Nunhems	5	20.5	7.5			2.08	61	4	4
B755	(L7550A x L1408B) x L9785B	671–4	1	10.5	16.5	5		2.77	32	4	4
B756	(L7550A x L2574B) x L9785B ☆	671–5		11.5	15.5	6		2.83	31	3.5	4
B757	(SC x L0567B) x L1408B	606–3	11	14	7	1		1.94	66	4	3.5
B758	HoneySnax	Nunhems	7	21	5			1.94	67	4	4
B759	(7551 x 1131) x 9785	475–3	1	16	13	3		2.55	44	4	4
B760	FCR 15457	Sakata	2	14	11	6		2.64	36	4	4
B761	PV5077	Pop Vriend	5	21.5	5.5	1		2.08	62	4	4
B762	(L9785A x L2576B) x L1408B	606–5	20	9	2	2		1.58	72	4	4
B763	(SC x L0567) x L9786B	673–2	1	9	17	5	1	2.88	29	4	4
B764	PV5198 ☆	Pop Vriend		1.5	13	13.5	5	3.67	5	4	4
B765	(SC x L2577) x L9793B	676–5	14	16	3			1.67	71	3.5	4
B766	L0574A x L9793B	677–4	10	14	9			1.97	65	4	4
B767	KXPC-520	Integra			14.5	16.5	2	3.62	7	4	4
B768	(L7550A x L1408B) x L9793B	676–3	2	19.5	9.5	1	1	2.38	54	4	4
B769	PV5102 ☆	Pop Vriend	4	21	8			2.12	59	4	4
B770	KXPC-506	Integra	1	18.5	9.5	4		2.50	47	4.5	4
B771	(L9785A x L2576B) x 2574B	615–5	4	14	11	4		2.45	48	3	3.5
B772	((S.C. x L1403) x L0567) x L9785B	671–2		18.5	11.5	3		2.53	46	3	4
B773	FCR 16517	Sakata	1	9.5	19.5	3		2.74	34	3.5	4
B774	PV5182	Pop Vriend	18	13	1	1		1.55	73	4	4
B775	((S.C. x L1403) x L4168) x L2577B	620–5	10	18	5			1.85	68	4	4
B776	((S.C. x L1403) x L0567) x L2577B	620–2	3	17	10	3		2.39	53	4	4

[1] Mean based on average of 33 judges: 1 = unacceptable, 2 = poor, 3 = fair, 4 = good, 5 = excellent.

[2] Flavor (1 judge): H = Harshness: 1=Very harsh, 5=Very mild;
S = Sweetness: 1=Not sweet, 5=Very sweet

Each ☆ indicates that one parent is a nematode resistant line

Table 2 (cont.). USDA Carrot Trial Results, DREC 2017

USDA California Carrot Trials 2017

Entry	Pedigree or Name	Source	Number of Judges Placing in Class 1	2	3	4	5	Mean[1]	Rank	Flavor[2] H	S
Novelty Trial											
T701	PV5232	Pop Vriend	3	4.5	16.5	3	1	2.80	13	4	3
T702	CreamPak	Nunhems	1	4.5	4	12.5	6	3.64	2	4	3.5
T703	Belveta	Seminis	5	7	13	3		2.50	15	4	3
T704	(L6038 x P6139) x 6143	640–3		4	6.5	14.5	3	3.59	3	4	4
T705	PV5173	Pop Vriend	4	5	13	4	2	2.82	12	4	3
T706	SnowMan	Nunhems	2	5.5	10.5	7	3	3.13	8	4	3.5
T707	PV5162	Pop Vriend	3	6	14.5	3.5	1	2.77	14	2.5	3.5
T708	(SC x 0148) x 8197	273-5		3	9.5	13.5	2	3.52	4	4	3
T709	Malbec	Seminis		2	10.5	15.5		3.48	5	3.5	4
T710	PV5134	Pop Vriend	3	5	11	7	2	3.00	9	2.5	3.5
T711	Purple Elite	Nunhems		6	11.5	7.5	3	3.27	7	3	3
T712	Red "A" x PR	127633	4	15	5	3		2.26	16	3.5	4
T713	PV5017	Pop Vriend	4	5	12.5	4.5	2	2.84	11	4	4
T714	YellowBunch	Nunhems	0.5	6	6.5	13	2	3.36	6	4	4
T715	Ruby Queen	Nunhems		2.5	9.5	10	6	3.70	1	4	4
T716	P1188A x Npw6163B	641–2	7.5	10.5	6.5	3.5		2.21	17	4	4
T717	PV5138	Pop Vriend	3	6	11	6	2	2.93	10	4	4

[1] Mean based on average of 28 judges: 1 = unacceptable, 2 = poor, 3 = fair, 4 = good, 5 = excellent.

[2] Flavor (1 judge): H = Harshness: 1=Very harsh, 5=Very mild;
S = Sweetness: 1=Not sweet, 5=Very sweet

Table 3. Progress in combining nematode resistance sources

	MJ	1091	WR	HM	PD	SFF	NF
MJ	--	*** 0-5	*** 1-3	*** 1-5.5	*** 0-5	*** 3-6	*** 0-3
1091		--		*** 1-3	** 2-4	*** 0-2	* 1-4
WR			--	*** 1-2	*** 3.5-4	** 2-3	* 1-3
HM				--	*** 0-2.5	*** 0-2	** 1-2
PD					--	* 1-3	** 2-3
SFF						--	*** 0-1.5
NF							--
Susc. Long	*** 0-1	*** 0.5-2	*** 2-3	*** 0-1	*** 0-2	*** 0-1	** 1-3
Susc. Flavor	*** 0-1	*** 0-2	*** 2-3	*** 0-1.5	*** 0-1	*** 0-1	** 2-3
Susc. Other	*** 0-1			*** 0-1	** 2-4	*** 0-1	

MJ = *Mj-1* from 'Brasilia 1252'
1091 = Resistance from 'Brasilia 1091'
WR = Resistance from 'Western Red'
HM = Resistance from 'Homs'
PD = Resistance from 'Ping Ding'
SFF = Resistance from 'Scarlet Fancy × Favourite'
NF = Resistance from 'Nantes Fancy'

Asterisks denote intercross generations at F_1, F_2, and F_3 or higher, respectively for *, **, and ***. Values below asterisks denote average MiR scores among several F_2 populations for a given cross among resistance sources (upper portion of the table), and best MiR scores among one or more F_1 hybrids with susceptible parents (lower portion of the table). Data is from South Coast and Kearney field trials.