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. 1263 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 103 advanced baby, 34 cello, 94 novel color inbreds, and 626 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. 65 cello and 99 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 7 baby, 4 cello, and 7 novel entries in the top 20 of their respective classes. This was the fifth year that we included nematode resistant inbreds as components to cello and cut & peel hybrids among USDA entries, and among the 20 top cello hybrids from the USDA program, 15 had an inbred parent derived from nematode resistant backgrounds and 5 had both resistant parents. This was our twelfth year to perform a specialty carrot trial that included 30 entries with unusual color or shape. Flavor evaluation was also performed for all entries.

3. Forty-five inbreds are being tested further by seed companies (listed in Table 1). Nineteen 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

1. *Incorporating Resistance from 'Brasilia' Germplasm*
   Studies we 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 another 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. 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. To accompany the release of 'Brasilia'-derived germplasm to the seed industry (Table 3), we have published information on markers (Parsons et al. Molec. Br., 2015).

   At the Kearney Station 892 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_9 generations. Several selections 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 more advanced generations were selected entries had excellent resistance to both *M. incognita* (MiR) and *M. javanica* (MjR). 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 an *Mj-1* single source of resistance or combinations of *Mj-1* and the chromosome 1 resistance 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 these inbreds is released (Table 3) 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 Kearney Station infested fields. Multiple entries were received from 5 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., 2014). Field evaluation of resistance derived from all these sources was tested at both the Kearney 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 (Table 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. 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. In fact, we recently 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., 2016). 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 four chromosomes 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 new combinations of genes and alleles was initiated in the last year to 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 4). We have produced seed of several F_2 through F_6 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. F_2 average scores were low (0-1) in several populations (see trial data in Dr. Roberts' report) from field trials at the Kearney Station (esp. among plots 101-106), 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 Kearney 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.

Seed samples of F_3, F_4 , and F_5 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'). 'Uberlandia' derivatives also had resistance scores in the range of 2-3 (plots 361-365; see Kearney results in Dr. Roberts' report) and had robust overall growth. Seed stocks derived from 'Uberlandia' will be evaluated to determine if resistance is due to the same genes already identified, or whether additional nematode resistance genes occur in carrots.

Greenhouse evaluation of carrots proven to have strong Mi resistance in previous collaborative research were evaluated for resistance response when exposed to several new nematode strains and species by Dr. Roberts (see his report) and selected roots were sent to Wisconsin. Seed production from 2015 was evaluated in 2016 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 resistant plants were grown in our DREC trials. Seed from segregating populations derived from the same parental stocks was tested in 2016 to initiate studies of the inheritance of cavity spot resistance. Detailed results of those evaluations are found in Dr. McDonald's report. In recombinant inbred lines of the cross used for our first nematode resistance evaluation, Brasilia x B6274, we observed a wide range of cavity spot resistance indicating a significant heritable basis for this trait (Table 5). Additional potential new sources of resistance will also be tested.

Roots of resistant plants from a wide genetic range of seed sources in those evaluations were shipped to Wisconsin and are being used in our winter 2016-2017 greenhouse seed production trials to develop seed stocks to better determine the genetic basis of resistance and advance our breeding program for resistance based upon Dr. McDonald's field evaluations.

E. Seed Production and Laboratory Analysis

1. Roots from California trials were sent to Wisconsin for seed production. Seed yields were average in our 95 cages and 743 breeding plot isolations in the summer, and average in 1254 greenhouse cages in the winter greenhouse. These roots were used to produce seed of 63 new experimental hybrids, and 297 new experimental breeding stocks for current and future testing.

2. Detailed flavor and texture evaluation was made on 123 populations and carotene was quantified in 28 of them to estimate nutritional value (see Table 1). Seed was sent to cooperators for testing. Of particular interest are nutritional properties in populations with elite nematode resistance. A range in color and nutritional value has been observed 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 12 new F_1 intercrosses combining unrelated sources of resistance, 17 F_2 populations segregating for multiple sources of resistance in California-adapted background, and 216 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 19 new F_1 intercrosses combining unrelated sources of resistance and generated 7 F_2 populations segregating for resistance in California-adapted background. These will be very valuable in future cavity spot resistance genetics and breeding.

F. Evaluation of Carrot Germplasm and Advanced Selections for Alternaria Leaf Blight Resistance and Production Characteristics

Field evaluation of *Alternaria dauci* resistance was performed in Wisconsin. Resistance was observed in 736 wild and 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. Molecular markers are being developed to track resistance. New genetic sources of resistance were mapped and crosses were made between these genetic stocks and inbreds adapted for production in California. Hybrid combinations are being developed for field testing.

G. Carrot Molecular Genetic Markers

With the carrot genome sequenced, we have identified hundreds of molecular markers linked to all major resistance QTL (Table 3). These markers are being used to select for nematode resistance in more diverse backgrounds and to identify candidate genes. 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										
1131	Long Red surrey x HCM	5	3	2	16		Taper	Cavity Spot Res.		Best Cavity Spot Resistance
1137	Good Flavor Mass	3	4	5	13		Intermediate	Cavity Spot Res.		Good cello parent
1138	HTDS/HRS	3	3	3	14	x	Blunt +	Cello		Good cello pollinator
Nb1175	8483 x 9256	4		3	28	x		Cello	MjR, MiR	Strong nematode resistance S.C.'10; High rank hybrid 2014 DREC
Nb1386	8483 x 9256	4		4	26			Nematode Res.	MjR, MiR	Strong nematode resistance Kearney'13
Nb1391	8483 x 9256	4		4	27	x		Nematode Res.	MjR, MiR	Strong nematode resistance Kearney 2013, '16
L1397	FN2-9 x 2302	4		4	29			CP		High Rank Hybrid 2013 DREC
L1408	FN2-9 x 2302	4		4	28			CP		High Rank Hybrid 2013, '16 DREC
2126	2566 x 3475	3	4	4	15	x	Blunt	CP, Cello	Sprangles =5	Good Hybrid Seed Parent
2144	3180 x 6274	4	4	3	20	x	Blunt	Cavity Spot Res.	Sprangles =5	Good Hybrid Seed Parent
Nb2155	BR x 6274	4		4	22			Cello	MjR, MiR	Strong nematode resistance S.C.'14, Kearney '16
Nb2159	BR x 6274	3		3	22	x		Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2015
Npw 2191	PD x WR	3		3	18			Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2016
Nb2195	BR x 6274	3		4	24			Nematode Res.	MjR, MiR	Strong nematode resistance S.C.'14
Nb2205	BR x 6274	4		4	23			Nematode Res.	MjR, MiR	Strong nematode resistance Kearney'13, S.C.'14
2226	HTDS/LRS	4		3	25			Cavity Spot Res.		Cello parent
L2301	FN2-9 x 9304	4		4	29			CP		High rank hybrid 2013, '15 DREC
Nbh2306	HM x (B x 6)	4	5	4	24			CP, Nematode Re	MjR, MiR	Strong nematode resistance Kearney'13, '16; S.C.'14
2327	5280 x HCM	5		3	27	x	Blunt	CP, Cello		High rank hybrid 2014, '15 DREC
L2574	FN2-9 x 2302	4		4	34			CP		High rank hybrid 2012, '13, '16 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
L2577	FN2-9 x 2302	4		4	29			CP		High rank hybrid 2012 DREC
3035	2126 x 2144	4	4	4.5	15	x	Intermediate	CP, Cello		Good Combining Ability, High rank hybrid 2015 DREC
Nb3271	BR x 6274	3		4	21			Nematode Res.		Strong nematode resistance, Kearney 2015
Nb3284	Nb8483 x 9256	4		4	24			Nematode Res.		Strong nematode resistance, Kearney 2014, '16
Nb3353	BR x 6274	3		3	22			Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2015
L4622	FN2-9 x 2302	4		4	27			CP		High rank hybrid 2014, '15 DREC
L4623	FN2-9 x 2302	4		4	28			CP		High rank hybrid 2014, '15 DREC
Nb5192	BR x 6274	4	4.5	4.5	20			Nematode Res.	MjR, MiR	Strong nematode resistance, Kearney 2014, '16
5367	EFM	3		4	17			Cavity Spot Res.		Cello pollinator
L6203	2566 x FN2-9	4	3.5	4+	22		Intermediate	Cello		Long ,Flavor Select
7241	8532 x FN2-9	3	4+	3	21	x	Intermediate	Cello	Blck Crwn =R	Good Combining Ability
L7550	FN2-9 x 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
AR8576	4367 x D.carota Ger.	3		4	16		Intermediate	Alternaria Res.		Medium Orange, Alternaria Resistant
Nb9324	8503 x Long	3		4	23	x		CP, Cello	MjR, MiR	S.C.'14 Mi and Mj =0 or 1
L9785	FN2-9 x 2302	4		4	30	x	Blunt	CP		High rank hybrid 2009, '13, '15 DREC
L9786	FN2-9 x 2302	4		4	31			CP		High rank hybrid 2015, '16 DREC
L9788	FN2-9 x 2302	4		4	29		Blunt	CP		High rank hybrid 2013, '15 DREC
L9791	FN2-9 x 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 x 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 x PI			4		x		Specialty		Purple Orange; Flavor Select
PR2356	7262 x 432903			4				Specialty		Purple Red; Flavor Select
W2383	BCVTHT x Wwortel			5				Specialty		White
Y3429	JOD x W. Belgian			4				Specialty		Dark Yellow, Flavor Select
R4294	Red x 7262			4		x		Specialty		Red, Flavor Select
Y4310	JOD x W. Belgian			4				Specialty Cello		Yellow
R5646	Red x 7262			3		x		Specialty		Red, Flavor Select
P6220	Trksh x 7262			4		x	Taper	Specialty		Purple, Flavor Select
PR6245	(7262 x Trksh) x Flavor			3.5		x	Blunt	Specialty		Purple Red
PR6318	7262 x PI 432903			3.5			Intermediate	Specialty		Purple Red
P6357	B7262 x Trksh			4			Intermediate	Specialty		Purple, Flavor Select
P6360	(Trksh x 7262) x Best Flavor			4		x		Specialty		Purple, High rank entry 2015 DREC
R6636	(432906PRC x 319858,432903) x FS			4		x		Specialty		Red
R6637	432906PRC x 319858JP			4.5			Blunt	Specialty	Nantes	Red
R8201	PI 432903			4		x		Specialty		Red; High rank entry 2013, '14 DREC
Y8519	Trksh x 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 2016

USDA California Carrot Trials 2016

Entry	Pedigree or Name	Source	Number of Judges Placing in Class 1	2	3	4	5	Mean[1]	Rank	Flavor[2] H	S
Cello Trial											
C601	Maverick	Nunhems			3.5	12.5	4	4.03		3	3
C602	(Nb8531xNb3999)xNb6526	086-5		10.5	12.5	5		2.80		3	3
C603	BX 3005	Bejo	2	0.5	12	10.5	3	3.43	2	3	3
C604	(SCxNb3999)xNb9324/4216 ☆☆	576-6	2	14.5	7.5	2	2	2.55	21	3	3
C605	SV2214DL	Seminis	1	1	5.5	15	5.5	3.82	1	3	3
C606	(5280 x 6366) x 7254	752-3	3	11	10.5	3.5		2.52	23	3	3
C607	(SCxNb8542)xNb9324/4216 ☆☆	576-11	14.5	8.5	3	2		1.73	50	3	3
C608	Choctaw	Nunhems	2	4.5	9.5	11	1	3.16	5	3	3
C609	(Nb4001xNb6526)xNb1386 ☆☆☆	512-7	6.5	14	5	2.5		2.13	37	3	3
C610	(3035 x Nb3999) x 2327 ☆	259-3	3	6.5	13.5	5		2.73	17	3	3
C611	KXPC-404	Integra	7.5	11.5	5	3	1	2.23	32	3	3
C612	(L7551 x 1131) x L0567	503-13	10	10	7	1		1.96	39	4	4
C613	VIL 6	Vilmorin	2	7.5	13	5.5		2.79	13	4.5	4
C614	(L9785 x L0567) x Nb1386 ☆	512-9	5	9	8.5	4.5	1	2.55	22	4	4
C615	(2327 x 2289) x 2303	526-3	5	8.5	12	1.5	1	2.46	27	3.5	4
C616	FCR 15560	Sakata	1	9	10	6.5	1.5	2.95	10	4	4
C617	(SC x Nb3999) x Nb1386 ☆☆	512-4	3	11.5	11.5	2		2.45	28	3.5	4
C618	(Nb1393 x L0569) x L2577 ☆	535-9	9	15	4			1.82	46	3	3
C619	Trooper	Nunhems	4	9.5	11	3	0.5	2.52	24	3	3
C620	BX 1133	Bejo	4	7	10	6	1	2.75	16	3	3
C621	(Nb8524xNb8483²)xNpw2191 ☆☆☆	518-4	19	5	2.5	1.5		1.52	53	3	3
C622	(3035 x Nb3999) x Nb6526 ☆☆	568-6	7	10	9	1	1	2.25	31	3	3
C623	KXPC-586	Integra	2	8.5	11	6.5		2.79	14	3	3
C624	(Nb8483 x Nbh2306) x L0567 ☆☆	503-12	11	11	5		1	1.89	44	3	3
C625	FCR 12089	Sakata	4	8.5	9.5	4.5	1.5	2.68	18	3	3
C626	(Nb1393 x L0567) x 5133 ☆	543-2	5	14.5	6.5	1		2.13	36	3	3
C627	Rebel	Nunhems	4	5	10	5.5	2.5	2.91	11	4	4
C628	(Nb8483xNb4216) x Nb2195 ☆☆☆	519-3	4	7.5	6.5	9		2.76	15	3	3
C629	(2327 x 2289) x 1131	509-4	12	8.5	6	0.5		1.81	47	3	3
C630	(Nb13932 x L0569) x Nb1175 ☆☆	510-4	8.5	13	5	0.5		1.91	43	3	3
C631	BX 1144	Bejo	6	16.5	4.5			1.94	41	3	3
C632	(Nb8483xNbh2306)xNb2195 ☆☆☆	519-2	9.5	8.5	7	1	1	2.09	38	3	3
C633	Maverick	Nunhems	3	8	13	3		2.59	19	3.5	4
C634	FCR 15562	Sakata	3	3	12	7.5	1.5	3.06	7	3	3
C635	(2327x2289)x((LRSxHCM)x2327)	562-3	10.5	8	7.5	1		1.96	40	3.5	4
C636	(L1406 x L1401) x Nb1175 ☆	510-5	19.5	6.5		1		1.35	55	3	3
C637	NUN 85021	Nunhems	2	5.5	10.5	8	1	3.02	8	3	3
C638	(L7551 x 1131) x 5133	543-8	13	8	3.5	1.5		1.75	49	3	3
C639	(Nb8483xNbh2306)xNb2205 ☆☆☆	521-2	2	7	11.5	6.5		2.83	12	3	3
C640	FCR 12073	Sakata	4	8	12.5	2.5		2.50	25	3.5	4
C641	(SC x L0569) x L1408	516-9	19.5	7.5				1.28	57	3	3
C642	(L1406 x L1401) x L5134	544-6	17.5	9.5				1.35	56	3	3
C643	(L1406 x L0567) x 5133	543-3	5	10	11	1		2.30	29	3	3
C644	(3035xNb3999)xNb9324/4216 ☆☆	576-7	6	13	5	2	1	2.22	33	3	3
C645	FCR 15561	Sakata	1	6	12.5	4	3.5	3.11	6	3	3
C646	(L7551A x 1131B) x L5134	544-8	12.5	11.5	3			1.65	51	3	3
C647	(SC x Nb3999) x Nb6526 ☆☆	568-7	4	9	11	3		2.48	26	3	3
C648	Bull Dog	Nunhems	2	4	11.5	6.5	3	3.17	4	3	3
C649	(SC x Npw2191²) x Nb9297 ☆☆	575-3	19	6	2			1.37	54	3	3
C650	(SC x Nb8542) x Nb1386 ☆☆	512-8	8.5	14.5	4			1.83	45	3	3
C651	KXPC-020	Integra	4	14.5	7.5	1		2.20	34	4	4

Continues next page

Table 2 (cont.). USDA Carrot Trial Results, DREC 2016

USDA California Carrot Trials 2016

Entry	Pedigree or Name	Source	Number of Judges Placing in Class 1	2	3	4	5	Mean[1]	Rank	Flavor[2] H	S
Cello Trial — Continued											
C652	(Nb8524xNb8483²)xNb9297 ☆☆☆	575-4	9	8	4	6		2.26	30	3	3
C653	(9785 x L2576) x Nb1175 ☆	510-7	5	14	7	1		2.15	35	3	3
C654	FCR 12070	Sakata	2	4.5	13	7.5		2.96	9	3	3
C655	(Nb1393 x L0569) x 5133 ☆	543-5	7	15.5	3.5	1		1.94	42	4.5	4
C656	SV4128DL	Seminis	2	2	8	13.5	1.5	3.39	3	3	3
C657	(Nb8524xNb8483²)xNb6526 ☆☆☆	568-8	20	2	2	3		1.56	52	3	3
C658	(SC x Nb3999) x Nb2205 ☆☆	521-5	5	7.5	9	4.5	1	2.59	20	3.5	4
C659	2327A x 2303B	B123-3	10.5	12.5	4			1.76	48	4	4
C660	FCR 15515 Nantes	Sakata	2	5	12	6	1	2.96		4	4
C661	FCR 14411 Nantes	Sakata	1	4.5	10	9.5	1	3.19		4.5	4
C662	FCR 15525 Nantes	Sakata	2	6.5	9.5	7	1	2.94		4	4
C663	FCR 15517 Nantes	Sakata	2	10.5	11.5	1	1	2.56		3.5	4
C664	FCR 15531 Nantes	Sakata	4	13	4	4	1	2.42		3.5	4
C665	FCR 15545 Nantes	Sakata	2	8	13	3		2.65		4.5	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

Each ☆ indicates that one parent is a nematode resistant line

Table 2 (cont.). USDA Carrot Trial Results, DREC 2016

USDA California Carrot Trials 2016

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											
B601	Imperial Cuts	Integra		3	7	11	2	3.52		4	4.5
B602	Propeel	Seminis			5	14	5	4.00		4	4.5
B603	UpperCut	Nunhems	2	4	12	5		2.87		4	4
B604	(S.C. x L0569) x L9786	578-2	2	10.5	13.5	5		2.69	53	3	3
B605	(L7551 x 1131) x L9788	477-2	1	4.5	13.5	12		3.18	24	3	3
B606	(9253 x L7551) x L0569	405-5	1	14	12	3	1	2.65	57	3	3
B607	FCR 11740	Sakata		3	13	12	2	3.43	12	3	3
B608	(S.C. x L1408) x L9786	578-4	2	7	16	5	1	2.87	36	3	3
B609	(L9785 x L0567) x Nb1175	510-3	4.5	18	5.5	3		2.23	81	3	3
B610	KXPC-222 (Skylar)	Integra	3	16	10.5	1.5		2.34	76	4	4.5
B611	(L1406 x L1401) x L2577	535-10	3.5	12	11.5	2	1	2.50	68	3	3
B612	S.C. x L05673	503-9	8.5	13.5	6	2		2.05	89	3.5	4
B613	(S.C. x L9788) x L9785	475-4	1	4	7	12.5	5.5	3.58	8	3	3
B614	FCR 15493	Sakata	1	4.5	11.5	11.5	1.5	3.27	20	3	3
B615	(L7550 x 2327) x L9786	476-4	5.5	15	8.5		1	2.20	83	3	3
B616	(S.C. x L0573) x L1408	516-4	5	11.5	6.5	6.5	0.5	2.53	65	3	3
B617	VIL 3	Vilmorin	5.5	12.5	10.5	1.5		2.27	80	3	3
B618	(S.C. x L1408) x L0567	503-4	5	11.5	11	2.5		2.37	74	3	3
B619	(L1406 x L1401) x L0567	503-11	10	13.5	5.5		1	1.95	94	3.5	4
B620	HoneySnax	Nunhems	1	6.5	12	9.5	1	3.10	27	3	3
B621	(S.C. x L1408) x L2577	535-4	3	9	11.5	4.5	3	2.85	38	3	3
B622	(S.C. x L2577) x L1408	516-6	1	12	14	4		2.68	54	3.5	4
B623	KXPC-506	Integra	2.5	6	15.5	7		2.87	37	3	3
B624	(9253 x L7551) x L9785	475-5		4.5	16.5	9	1	3.21	22	3	3
B625	(L9785 x L0567) x L5134	544-4	7	16.5	5.5	1		2.02	92	4	4
B626	1441	Seminis		3	14.5	8.5	4	3.45	11	4.5	4
B627	(S.C. x L9788) x L6191	491-2	3	3.5	20.5	2	1	2.82	46	4	4.5
B628	(S.C. x L4623) x L2575	533-7	10.5	16	2.5		2	1.94	95	4	4
B629	FCR 10718	Sakata	3.5	10.5	12.5	2.5	2	2.65	58	4	4
B630	(L7551 x 1131) x L9785	475-3	2.5	6.5	15.5	4.5	2	2.90	34	4	4
B631	(S.C. x L4623) x L2574	531-7	4.5	14.5	11	1		2.27	79	4	4
B632	VIL 4	Vilmorin	2	5	19.5	4.5		2.85	39	4	4
B633	(9253 x L7551) x L2576	425-4		1	13	13	4	3.65	5	4	4
B634	(9253 x L7551) x L6190	490-3	1	2.5	7	14.5	5	3.67	4	3.5	4
B635	CrispyCut	Nunhems		1	8	18	4	3.81	3	3	3
B636	(L1406 x L0567) x Nb1175 ☆	510-2	3	15	10	3		2.42	72	3	3
B637	(9253 x L7551) x L6191	491-4	1	10	12.5	7.5		2.85	40	4.5	4.5
B638	KXPC-520	Integra	2	7.5	11.5	7.5	1.5	2.97	32	4.5	4
B639	(L7550 x 2327) x L9786	476-5		5.5	11.5	10	4	3.40	13	3	3
B640	(Nb1393 x L0569) x L2577 ☆	533-9	6.5	13	5.5	3.5	2.5	2.44	70	3	3
B641	(S.C. x L2576) x L9786	578-5	5	17.5	6.5	2		2.18	84	3	3
B642	VIL 1	Vilmorin	1	5	15	9.5	0.5	3.11	26	3	3
B643	(L9785 x L2576) x L5134	544-7	1	10.5	14	5.5		2.77	48	3	3
B644	(7254 x L7551) x L6190	490-5	3	8.5	12	6	1.5	2.82	44	3	3
B645	(S.C. x L1408) x L2574	531-4		4.5	3.5	14.5	8.5	3.87	2	4	3.5
B646	SlenderCut	Nunhems	1	4.5	11	11.5	3	3.35	16	3	3
B647	(L1406 x L0567) x L5134	544-3	3.5	10	12	5.5		2.63	60	4	4
B648	Imperial Cuts	Integra	1.5	8	16	5.5		2.82	45	4	4.5
B649	(9253 x L9788) x L2304	247-5	4.5	7.5	14.5	4.5		2.61	62	4	4.5
B650	(9253 x L7551) x L6190	490-4	2	8	11.5	8.5	1	2.95	33	3	3
B651	CR 1640	Seminis	2	3	14	8.5	3.5	3.27	19	3	3

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Table 2 (cont.). USDA Carrot Trial Results, DREC 2016

USDA California Carrot Trials 2016

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											
B652	(9253 x L9788) x L2574	156-6	2	9.5	12.5	7		2.79	47	3	3
B653	(S.C. x L2577) x L9786	578-6	1.5	8	15.5	5.5	0.5	2.85	41	4	4
B654	9253 x 9788B2	477-5	2	9	17.5	2.5		2.66	56	3	4
B655	Istanbul	Bejo	7	18	3	3		2.06	88	4.5	4
B656	(Nb1393 x L0567) x L5134 ☆	544-2	2	9.5	12	6.5	1	2.84	42	3	3
B657	(S.C. x L25762) x L2574	531-5	9.5	16	5.5			1.87	96	4	4
B658	(9253 x L9788) x L9785	286-7	0.5	5	17.5	8		3.06	29	3.5	4
B659	KXPC-060	Integra	3	7.5	14.5	6		2.76	49	4	4
B660	(S.C. x L0569) x L2577	535-2	2	7.5	11.5	9	1	2.98	31	4	4
B661	(9253 x L7551) x L2576	425-3	1	11	13.5	2.5	1	2.71	52	4	4
B662	(7254 x L7551) x L6191	491-5	6	17.5	4.5	2		2.08	86	4	4
B663	FCR 14336	Sakata	1.5	7	11	9	1.5	3.07	28	4	4
B664	(Nb1393 x L0569) x L9786 ☆	578-9	11	10.5	7	1.5		1.97	93	4	4
B665	(S.C. x L05693) x L4168	540-2	5	19	6			2.03	91	4	4
B666	Propeel	Seminis	1	5	10.5	8.5	5	3.38	14	4	4
B667	(S.C. x 2327) x L9785	287-3	3	11	13	3		2.53	66	4	4
B668	KXPC-576	Integra	3	11	13	2	1	2.57	63	4	4
B669	(Nb1393 x L0569) x L5134 ☆	544-5	5	12.5	9	1.5	2	2.43	71	4	4
B670	(9256 x L7551) x L2301	245-4	4	13	11.5	1.5		2.35	75	4	4
B671	(S.C. x L1408) x L4168	540-4	5.5	15	7	2.5		2.22	82	3.5	4
B672	CR 1706	Seminis	1.5	3.5	11	10	4	3.38	15	3	3
B673	(S.C. x L1403) x L9786	578-3	4	8.5	14	3.5		2.57	64	3	3
B674	(S.C. x L2577) x L4168	540-6	1	11.5	11	5.5		2.72	50	3	3
B675	(9253 x L7551) x L6191	491-3		3	11.5	12	2.5	3.48	10	3	3
B676	NUN 85931	Nunhems	1	4.5	11.5	10.5	2.5	3.30	18	3	3
B677	(9253 x L7551) x L2304	247-3	4	6.5	10	9.5		2.83	43	3	3
B678	(L7553 x 2327) x L4623	362-3		7.5	10.5	11	1	3.18	23	3	3
B679	(L7553 x 2327) x L9786	476-3	3	16.5	9	0.5	1	2.33	77	3	3
B680	KXPC-516	Integra	2.5	5	9.5	10.5	1.5	3.12	25	3.5	4
B681	S.C. x L9788B[2]	477-3	5.5	10.5	13	1		2.32	78	3	3
B682	(S.C. xL2577) x L2574	531-6	5.5	7	10.5	6	1	2.67	55	3	3
B683	(2144 x 6253) x L2575	157-3	4.5	5.5	14	6		2.72	51	3	3
B684	FCR 15514	Sakata	2	4	5.5	9.5	8	3.60	6	3.5	4
B685	(S.C. x L9788) x L4622	363-3		6.5	10	9.5	3	3.31	17	3	3
B686	UpperCut	Nunhems	2	6.5	14.5	7		2.88	35	3	3
B687	(9256 x L7551) x L9788	477-4	6	16.5	6.5	1		2.08	87	3	3
B688	KXPC-107 (Starr)	Integra	2	4.5	8.5	14	1	3.25	21	3	3
B689	(S.C. x L1403) x L2575	533-3	4	8.5	12.5	4.5	0.5	2.63	59	3.5	4
B690	VIL 2	Vilmorin	5	11.5	10	3.5		2.40	73	3	3
B691	(S.C. x 1403) x L2574	531-3	7	13.5	7	2.5		2.17	85	3	3
B692	FCR 15511	Sakata		4	9.5	11.5	5	3.58	9	3	3
B693	(S.C. x L2577) x L0567	503-6	3.5	10	11	5.5		2.62	61	4	4
B694	SV2765DC	Seminis		1.5	3	15	10.5	4.15	1	4.5	4
B695	(L1406 x L1401) x 5133	543-6	4	9	16	1		2.47	69	4.5	4
B696	CandySnax	Nunhems	1	0.5	10	16.5	2	3.60	7	4.5	4
B697	(L9785 x L2576) x 5133	543-7	9	10.5	10.5			2.05	90	4	4
B698	KXPC-585	Integra	1.5	6	13.5	9		3.00	30	3	3
B699	VIL 5	Vilmorin	4	9.5	14.5	1	1	2.52	67	3	3

[1] Mean based on average of 31 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 2016

USDA California Carrot Trials 2016

Entry	Pedigree or Name	Source	Number of Judges Placing in Class 1	2	3	4	5	Mean[1]	Rank	Flavor[2] H	S	Color
Novelty Trial												
T601	White Satin	Bejo	1		3	2	1	3.29	6	4	5	White
T602	Snow Man	Nunhems	1	1	2.5	1.5	1	3.07	11	4	5	White
T603	Yellowstone	Bejo		1.5	2	2.5	1	3.43	5	3.5	4	Yellow
T604	(S.C. x Z021) x Y8519	574-3	5	1	1			1.43	30	3.5	4	Yellow
T605	YellowBunch	Nunhems		1.5	4	1.5		3.00	12	3.5	4	Yellow
T606	Mello Yello	Bejo		2	1.5	3	0.5	3.29	7	3	4	Yellow
T607	CreamPak	Nunhems			3	1.5	2.5	3.93	1	4	4.5	Cream
T608	TI-115	Takii	1	1	5			2.57	18	4.5	4	Orange
T609	Rainbow	Bejo	1		2.5	1.5	1	3.25	8	4.5	4	Mixed
T610	(S.C. x R6259) x R8201	275-3	1	1.5	3.5	1		2.64	16	4	4	Red
T611	R6637	370-1	1.5	2.5	1	2		2.50	19	4	4	Red
T612	R8201 x R0148	101-4	1.5	3	1.5	1		2.29	26	4	3.5	Red
T613	R.S.C. x (R0148 cg R6220)	252-4		3.5	3.5			2.50	20	4	4	Red
T614	TI-126	Takii	0.5	1.5	3.5	1.5		2.86	14	3.5	4	Red
T615	(S.C. x R6220) x R8201	275-2	0.5	3.5	2	1		2.50	21	3	4	Red
T616	R.S.C. x R8197	067-3	1.5	1.5	1.5	1.5		2.50	22	3.5	4	Red
T617	(R.S.C. x R6259) x R8197	273-5		2		3.5	1.5	3.64	3	4	4	Red
T618	R.S.C. x R8201	131-2	1	3.5	0.5	1		2.25	27	4.5	4	Red
T619	Purple Sun	Bejo	1	0.5	2	1.5		2.80	15	3	4	Purple
T620	(P6139A x P6245) x P6360	125-5	1	0.5	3.5			2.50	23	4	4	Purple
T621	Purple Haze	Bejo	2	0.5	3	0.5		2.33	25	4	4	Purple
T622	(Nb8483xNbh2306)xNpw2191☆☆☆	518-2	2.5	0.5	2			1.90	29	3.5	4	Purple
T623	NUN 89682	Nunhems	1		2	1	1	3.20	9	3.5	4	Purple
T624	(Nb8483xNbh4216)xNpw2191☆☆☆	518-3	2	2	2			2.00	28	3.5	4	Purple
T625	S.C. x R6259) x R8197	273-4	1.5	1.5	1	2		2.58	17	3	4	Red
T626	Deep Purple	Bejo		1	1.5	1.5	2	3.75	2	4	4	Purple
T627	P6139	656-1		1	4	1		3.00	13	4	4	Purple
T628	PurpleElite	Nunhems		1.5	1.5	1	2	3.58	4	3.5	4	Purple
T629	P.S.C. x P5401	558-2	1	3	1.5	1.5		2.50	24	4	4	Purple
T630	P.S.C. x P6139	060-2		2	2.5	2	0.5	3.14	10	4	4	Purple

[1] Mean based on average of 7 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. USDA,ARS – UC Riverside jointly developed and released nematode resistant carrot germplasm derived from three diverse unrelated genetic backgrounds and chromosomal regions with resistance genes conferring *M. incognita* resistance

Inbred	Source of Resistance	Generation	Remarks
Nb3999	'Br 1252'	F_3M	11-13 cm, orange, blunt
Nb4001	'Br 1252'	F_3M	14-16 cm, orange, blunt
Nb4002	'Br 1252'	F_3M	16-19 cm, orange, blunt
Nb6526	'Br 1252'	F_4	19-22 cm, orange, blunt
Nb8503	'Br 1252'	F_3M	11-12 cm, orange, blunt
Nb resistance genes on chromosomes 1 (67 cM) and 8 (42 cM)			
Nh2168	'Homs'	F_7	14-17 cm, purple yellow/orange, blunt
Nh resistance genes on chromosomes 1 (35 cM), 2 (43 cM & 63 cM), 8 (42 cM), 9 (10 cM)			
Ns5154	'Scarlet Fancy' x 'Favourite'	F_6M	11-14 cm, orange, blunt
Ns resistance genes on chromosomes 4 (33 cM) and 8 (42 cM)			

Research leading to the development of this germplasm was supported by CFCAB, USDA-SCRI, and USDA-OREI.

Table 4. 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	**8 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					--		*8 2-3
SFF						--	*** 0-1.5
NF							--
Susc. Long	*** 0-1	*** 0.5-2	*** 2-3	*** 0-1	*** 0-2	*** 0-1	
Susc. Flavor	*** 0-1	*** 0-2	** 2-3	*** 0-1.5	*** 0-1	*** 0-1	** 2-3
Susc. Other	*** 0-1			*** 0-1		*** 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.

Table 5. Cavity spot resistance variation in inbreds derived from 'Brasilia' x B6274

Inbred	14 Nov. % Disease incidence*	14 Nov. Disease Severity Index*
Nb 6526	6.8	3.6
Nb 2159	7.2	2.8
Nb 3271	16.2	7.0
Nb 3284	16.6	7.7
Nb 1393	17.3	8.2
Nb 1391	17.9	8.6
Nb 8524	18.7	9.4
Nb 4002	19.9	10.8
Nb 4001	22.3	11.8
Nb 1175	29.7	16.6

* *From M. R. McDonald CFCAB Report*