Registration of FC1018, FC1019, FC1020, and FC1022 Multigerm Sugarbeet Pollinator Germplasms with Disease Resistance

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ABSTRACT

FC1018 (Reg. No. GP-273, PI 658059), FC1019 (Reg. No. GP-274, PI 658060), FC1020 (Reg. No. GP-275, PI 658061), and FC1022 (Reg. No. GP-276, PI 658062) sugarbeet (*Beta vulgaris* L.) germplasms were released in 2009 from seed lots 05-FC1018; 05-FC1019; 07-, 08-, or 09-FC1020; and 05-FC1022, respectively, and tested under those designations. They were developed by the USDA-ARS at Fort Collins, CO and Salinas, CA in cooperation with the Beet Sugar Development Foundation, Denver, CO. All four germplasms are populations in fertile cytoplasm and segregate for self-sterility, multigermity, hypocotyl color, and the *Rz1* gene, which confers resistance to some strains of *Beet necrotic yellow vein virus*, the causal agent of rhizomania. FC1018, FC1019, and FC1020 have moderate tolerance to root-rotting strains (AG-2–2) of *Rhizoctonia solani* Kühn (the causal agent of Rhizoctonia root and crown rot), *Cercospora beticola* Sacc. (the causal agent of Cercospora leaf spot), *Beet curly top virus* (BCTV), and *Aphanomyces cochlioides* Drechsl., which causes Aphanomyces root rot (Aphanomyces black root). They are populations that can be used to select disease-resistant, multigerm pollinator parents. FC1022 has a moderate tolerance to BCTV and had a relatively high sucrose concentration at Salinas when tested in a field infested with rhizomania. Because of a large percentage of monogerm seedballs (45%) and O-type parentage, it should be possible to select monogerm, O-type lines from FC1022.

In sugarbeet (*Beta vulgaris* L.), Rhizoctonia root or crown rot of the mature root is caused by *Rhizoctonia solani* Kühn (AG-2–2) (Panella and Ruppel, 1996). Root rot is endemic in growing areas across the United States and an increasing problem worldwide (Panella, 2005; Windels et al., 2009). In the United States an estimated 24% of the sugarbeet acreage is affected, with losses of up to 50% of the crop (Windels et al., 2009). Within and among different anastomosis groups, there can be differences in virulence and pathogenicity, and a bioassay is required to confirm both pathogenicity and virulence (Herr and Roberts, 1980; Windels and Nabben, 1989, Panella, 2005).

Short rotations and the expansion of sugarbeet into fungi-infested areas have compounded the problem. The result is a reduction in net returns to growers, as well as processing losses due to reduced sucrose and purity from rotted or partially rotted beets. The use of Quadris fungicide (Syngenta, Basel, Switzerland) provides the first effective chemical protection for this disease. However, the timing of application is crucial for managing the disease (Stump et al., 2004). Additionally, spot spraying can be time consuming, and spraying a whole field because of a few patches of disease can be expensive. The use of resistant germplasm, coupled with crop rotation and other cultural practices, can provide excellent management of diseases caused by *R. solani*. John Gaskill began breeding for resistance in the late 1950s and released the first resistant germplasm in 1966 (Gaskill, 1968). Current Rhizoctonia-resistant germplasm has a level of resistance in which there is no yield loss under disease pressure in the field (Ruppel and Hecker, 1994). These germplasms combine resistance to Rhizoctonia root and crown rot with resistance to rhizomania (caused by *Beet necrotic yellow vein virus*; BNYVV) in a background containing acceptable yield characteristics and resistance to other diseases (Panella, 2005).

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Abbreviations: BCTV, *Beet curly top virus*; BNYVV, *Beet necrotic yellow vein virus*; CLS, Cercospora leaf spot; DI, disease index; MR, mother roots.

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Methods

Early-Generation Population Development

Development of 20031022 at Fort Collins

Sugarbeet roots from FC709–2 (PI 599668) (37 pollen donors) and FC907 were harvested from field trials, vernalized, planted, grown, and crossed in the greenhouse (FC709–2: red hypocotyls, male; FC907 green hypocotyls; female). Hypocotyl color of the offspring was used to identify the hybrids, producing population 19961009H2 (from 46 FC907 plants harvested) (Panella, 1999; Panella et al., 2008). FC709–2 has excellent resistance to Rhizoctonia root and crown rot and moderate resistance to Cercospora leaf spot (CLS; caused by *Cercospora beticola* Sacc.). It is mostly self-sterile and multigerm. FC907 is a breeding line that originated from FC607 (PI 590837) × FC701 (PI 590661) BC_4 (Garry Smith, personal communication, 1995) with FC607 as the recurrent parent (Hecker and Gaskill, 1972; Smith and Ruppel, 1980). The purpose of this cross was to combine the CLS resistance of FC607 with the multigerm trait of FC701. The resulting population, FC907, had excellent resistance to CLS and was more than 90% monogerm, but its resistance to Rhizoctonia root rot was poor (when tested as FC907–1) (Panella and Hanson, 2001).

Two-hundred fifteen red-hypocotyl plants from 19961009H2 (5.6% red) were bulk increased in the greenhouse to produce 19961023. Approximately 1000 plants of 19961023 were screened in a nursery artificially inoculated with *R. solani* AG-2–2 (isolate R9) as previously described (Ruppel et al., 1979; Panella, 1998). Of the 98 roots selected, 5 remained vegetative and 74 were harvested for seed, producing population 19981009H. When screened for resistance to Rhizoctonia root rot in an artificially inoculated nursery in 1999, 19981009H was significantly better than the susceptible control and significantly worse than the resistant control (data not shown). Seed was sown from 19981009H, and after vernalization, individual plants were bagged at flowering and harvested, generating 55 selfed families (19991004-xs). There were 32 selfed families with sufficient seed to screen for resistance to CLS in a nursery that had been artificially inoculated with *C. beticola* (Ruppel and Gaskill, 1971; Panella, 1998). Based on performance, 103 roots from eight families were dug, vernalized, and increased in bulk, with 63 surviving to produce seed, which was designated 20001009.

In 2001, the cross 20001009 × C931 (PI 636340), was made in the greenhouse using MR that had been harvested in the summer of 2000 and vernalized that fall (Lewellen, 2006). Approximately 100 plants of 20001009 provided pollen to male sterile (*aa*) individuals of C931. C931 has moderate resistance to a broad spectrum of diseases—including beet curly top (caused by *Beet severe curly top virus* [BSCTV] or closely related species), virus yellows (caused by *Beet chlorosis virus* and *Beet yellows virus*), powdery mildew [caused by *Erysiphe polygoni* DC. (syn. *E. betae* Weltzien)], Erwinia (caused by *Erwinia carotovora* subsp. *betavasculorum* Thomson et al.)—and contains the *Rz1* gene for resistance to rhizomania (Lewellen, 2006).

Seed from 74 plants was harvested and designated 20011013H2. That seed was planted in the field in 2001. The roots were dug late in August, vernalized, and planted in the greenhouse. Seed was produced on approximately 120 plants during the winter of 2001–2002 and was designated 20021002. That seed was then planted in the field in 2002, and the roots were dug, vernalized, and 66 roots were bulk increased to produce population 20031022.

Development of 20031018 and 20031019 at Fort Collins

Sugarbeet roots from C931 (24 pollen donors) and FC709–2 were dug from field trials in September and vernalized. After 120 d of vernalization, they were crossed in the greenhouse (C931: red hypocotyl, male; FC709–2: green hypocotyl, female), and hypocotyl color was used to mark the true hybrids , which constituted population 20011012H2 (74 plants harvested). FC709–2 has excellent resistance to Rhizoctonia root and crown rot and is mostly self-sterile and multigerm (Panella, 1999, 2000; Panella and Hanson, 2003, 2006). The cross combined the Rhizoctonia resistance of FC709–2 with the broad-spectrum resistance and agronomic performance of C931 (Lewellen, 2006). One hundred three red-hypocotyl plants from 20011012H2 (0.75% red) were bulk increased in the greenhouse, giving rise to 20011058. A bulk increase of 77 plants produced population 20031018.

Sugarbeet roots from a cross between FC712 (PI 590766) (24 pollen donors) and C931 were harvested from field trials, vernalized, and crossed in the greenhouse; hypocotyl color was used to identify the hybrids (FC712: red hypocotyl, male; C931: green, hypocotyl, female), which became population 20011011H2 (25 plants harvested). FC712 combines nine of the best sources of resistance to Rhizoctonia root and crown rot available within the ARS Fort Collins breeding program and has excellent resistance to this disease (Hecker and Ruppel, 1986; Panella, 1999, 2000; Panella and Hanson, 2003, 2006;). FC712 is mostly self-sterile and multigerm (Hecker and Ruppel, 1986). This population combined an additional source of Rhizoctonia resistance with the rhizomania resistance of C931 (Lewellen, 2006). One hundred thirty-seven red hypocotyl plants from 20011011H2 were bulk increased in the greenhouse to produce 20011060. 20031019 resulted from a bulk increase of 56 plants of 20011060.

In April 2004, seed of 20031018, 20031019, and 20031022 was sent to Salinas, CA.

Final Population Development and Selection at Salinas

The seed of these three populations was planted in the Spence field nursery (Salinas, CA) in April 2004, thinned, inoculated with *C. beticola*, but the rhizomania infection was natural. After 6 mo, mother roots (MR) were dug and individual roots were visually selected for freedom from certain diseases (CLS, rhizomania, powdery mildew), size, and shape, then processed in the sugar laboratory and selected for sucrose content (in December). Forty-seven MR were selected from 20031018 and averaged 18.5% sugar; 32 MR were selected from 20031019, which averaged 18.0% sugar;

and 47 MR were selected from 20031022, which averaged 20.2% sucrose. These roots were vernalized at 6°C under continuous light for 120 d, and each line was planted in a greenhouse isolation chamber at Salinas (Panella et al., 2008). Seed was harvested in bulk from each population and designated as 05-FC1018, 05-FC1019, and 05-FC1022.

Seed of 05-FC1018, 05-FC1019, and 05-FC1022 was planted in the Spence field nursery in 2006, thinned, and inoculated with Erwinia and *C. beticola*. Infection with BNYVV was naturally occurring. After 6 mo, mother roots were dug, and individual roots were visually selected for freedom from certain diseases (Erwinia, CLS, rhizomania, powdery mildew), size, and shape, then processed in the sugar lab and selected for sucrose content (in December). Mother roots of 05-FC1018 (17 MR), 05-FC1019 (16 MR), and 05-FC1022 (16 MR) were selected and vernalized for 120 d. All 49 of the roots from the three populations were planted together in an isolation chamber, bulk increased, and designated as 07-FC1020.

Seed of 07-FC1020 was sent to Medford, OR, where it was planted in August 2007 in the field to produce stecklings. In February 2008, vernalized stecklings were sent to Salinas, where they were bulk increased (54 plants) in an isolation chamber without selection. This increase was designated as 08-FC1020. In August 2008, seed of 08-FC1020 was planted in the Medford, OR, steckling field, and the vernalized stecklings (47 plants) were bulk increased without selection to produce 09-FC1020.

Seed of 05-FC1018, 05-FC1019, and 05-FC1022 was also sent to Medford, OR, where it was planted in August 2005 in the field to produce stecklings. In February 2006, vernalized stecklings were sent to Salinas, where 31 stecklings from each line were bulk increased in an isolation chamber without selection. This increase was designated as 06-FC1020.

Characteristics

Agronomic and Morphological Description

FC1018 (Reg. No. GP-273, PI 658059), FC1019 (Reg. No. GP-274, PI 658060), FC1022 (Reg. No. GP-276, PI 658062), and FC1020 (Reg. No. GP-275, PI 658061) were released in 2009 from the seed lots 05-FC1018, 05-FC1019, 05-FC1022, and 07-, 08-, or 09-FC1020, respectively. All four germplasms have a fertile cytoplasm. They are predominately multigerm but do segregate for the monogerm seed-ball trait—FC1018: 18% monogerm; FC1019: 25% monogerm; FC1022: 45% monogerm; and FC1020 (09-FC1020): 18% monogerm. FC1022 and, to a lesser extent, FC1020 segregate for O-type (maintainer of CMS equivalents), but they have not been tested to determine the percentage of plants that express restorer genes (Owen, 1945; Bliss and Gabelman, 1965; Theurer and Ryser, 1969). The population segregates for genetic male sterility (*aa*) and self-sterility (S^s), because self-fertility was introduced through C931 (Lewellen, 2006). All the populations segregate for hypocotyl color. FC1018 had 36% green hypocotyls (of 64 seedlings counted), FC1019 had 51% green hypocotyls (of 91 seedlings counted), FC1020 (09-FC1020) had 26% green hypocotyls (of 119 seedlings counted), and FC1022 had 35% green hypocotyls (of 62 seedlings counted). When tested for germination in September 2009, FC1018 had 64 sprouts per 100 seedballs, FC1019 had 91, FC1022 had 119, and FC1020 (09-FC1020) had 62 sprouts. Because multigerm seedballs often contain more than one viable embryo, it is possible to have more than 100 sprouts per 100 seedballs.

Resistance to Disease and Other Pests

Rhizomania

FC1018 (05-FC1018), FC1019 (05-FC1019), FC1022 (05-FC1022), and FC1020 (07-FC1020) were evaluated in 2006 and 2008 for yield when tested in fields infested with rhizomania (Table 1). To determine the disease index (DI) for rhizomania, the plots were partially topped, the beets were lifted and laid out on the soil surface, and the roots were individually scored for rhizomania. The DI was the average score of each plant within the entry on a scale of 0–9, where 0 = normal root, and 9 = very severe rhizomania or dead. With severe rhizomania, the reaction of the *Rz1* gene can often be divided into roots with ratings of 0–4 for resistance and 5–9 for susceptibility. Categories of percent resistant (0–3, 0–4, or 0–5) were calculated by adding the numbers of roots in each DI class of the category and then dividing by the total number of roots rated for all classes (Table 1). FC1018, FC1019, and FC1022 all performed significantly better than the susceptible check in test 3106, although not as well as the *Rz1* (rhizomania resistant) hybrid check, 'Beta 4430R'. In tests 1908 and 1208, FC1020 was not significantly different from the *Rz1* hybrid check, 'Beta 4430R', and in test 1208, FC1020 was significantly better than the susceptible check.

Cercospora Leaf Spot

The germplasms were evaluated by Betaseed (Shakopee, MN) personnel in a field nursery for resistance to CLS at Rosemount, MN, during and after selection for resistance to rhizomania (Table 2). All plots were two rows, 3 m long with 56-cm row spacing. The seed was treated with Allegiance and Thiram (Bayer CropScience, Research Triangle Park, NC) and Tachigaren (Sankyo Agro Co. Ltd., Tokyo, Japan). Trials were planted in early May and thinned to a uniform stand of 17 cm between plants. The nursery was inoculated during the first 2 wk of July with a 2:1 mixture of talc to dry *C. beticola*–infected leaves at a rate of 16.8 kg ha^{-1}. Solid set irrigation was used to provide adequate moisture for initial infection and as needed to maintain conditions favorable for CLS development. The KWS rating scale (Kleinwanzlebener Saatzucht, 1970) was used to evaluate leaf-spot infection. A rating of 1 indicates an absence of leaf spot spots, and 9 indicates that the leaves that are entirely necrotic. Ratings were taken each week during the period of infection. The experimental design was an RCB with three replications (M. Rekoske, personal communication, 2006; J. Miller, personal communication, 2008).

FC1018 had a significantly lower disease rating than the susceptible check and was not different from the Betaseed tolerant nonhybrid check or the USDA-ARS tolerant check in the mild Cercospora epidemic in 2008 (Table 2). In 2006 and 2008, FC1018 had a significantly lower disease rating

Table 1. Sugar yield, root yield, and sucrose content of FC1018 (05-FC1018), FC1019 (05-FC1019), FC1022 (05-FC1022), and FC1020 (07-FC1020), the experimental hybrids of FC1018, FC1019, and FC1022, and checks when grown in fields infested with rhizomania in Salinas, CA in 2006 and 2008.

					Resistance to Rhizomania					
Variety	Description	Sugar yield[†]	Root yield	Percent sugar[‡]	DI score	0–3	0–4	0–5	Canopy score	Yellowing score
		kg ha^{-1}	Mg ha^{-1}	%	0–9[§]		%R[¶]		1–5[#]	0–9[††]
Test 1906[‡‡]										
05-FC1022	FC1022	10485	62.2	16.9					2.4	
05-FC1018	FC1018	9322	57.6	16.2					2.5	
05-FC1019	FC1019	11267	70.2	16.0					2.4	
Beta 4430R	*Rz1*[§§] check	13318	85.0	15.6					1.5	
Roberta	*rzrz* check	8310	61.1	13.6					3.9	
Angelina	*Rz1*+ *Rz2* check	14351	87.3	16.5					1.3	
Phoenix	*Rz1* check	10959	73.7	14.9					1.6	
$LSD_{0.05}$		936	5.5	0.6					0.5	
CV		9	8.0	3.8					25.1	
Test 3106[¶¶]										
05-FC1022	FC1022	12010	66.4	18.2	3.8	57.1	68.7		2.0	
05-FC1018	FC1018	11160	64.5	17.4	3.9	53.0	66.0		2.2	
05-FC1019	FC1019	13142	78.3	16.8	3.9	52.8	71.2		1.7	
05-FC1022H50[##]	C790–15CMS × FC1022	11684	66.4	17.6	3.5	71.3	80.3		2.2	
05-FC1018H50	C790–15CMS × FC1018	12092	69.9	17.3	3.9	55.8	65.2		2.5	
05-FC1019H50	C790–15CMS × FC1019	11924	73.0	16.3	3.9	54.9	65.1		2.3	
Beta 4430R	*Rz1* check	14365	82.3	17.5	2.9	90.1	93.5		2.2	
Roberta	*rzrz* check	5498	38.8	14.0	5.5	7.2	10.0		4.0	
Angelina	*Rz1*+ *Rz2* check	14860	85.6	17.4	3.1	85.1	96.4		1.3	
HH142		15625	89.6	17.5	3.3	73.2	90.0		1.7	
$LSD_{0.05}$		2151	12.5	0.8	0.5	18.6	17.1		0.6	
CV		16	15.5	4.3	11.2	26.1	20.3		25.2	
Test 1908[†††]										
07-FC1020	FC1020	9262	61.9	15.0	6.4		22.0	38.7		3.0
Beta 4430R	*Rz1* check	6506	43.9	14.6	6.0		23.8	44.5		3.0
Roberta	*rzrz* check	3363	26.3	13.8	7.6		4.9	18.6		4.9
Angelina	*Rz1*+ *Rz2* check	14111	83.3	17.0	4.8		45.8	70.0		0.6
Beta G017R	*Rz2* check	16098	102.3	15.8	4.2		51.7	81.2		0.3
LSD (.05)		3578	23.5	1.4	1.3		23.7	25.4		1.4
CV (%)		31.5	31.16	6.4	15.6		67.8	40.0		36.7
Test 1208[‡‡‡]										
07-FC1020	FC1020	5090	32.7	15.6	7.4		8.1	19.4		4.5
Beta 4430R	*Rz1* check	3994	28.8	13.3	7.7		4.4	12.8		5.2
Roberta	*rzrz* check	3974	31.3	12.7	8.3		2.6	5.0		5.9
Angelina	*Rz1*+ *Rz2* check	9733	60.2	15.2	5.3		39.1	57.5		1.9
Beta G017R	*Rz2* check	9709	65.0	14.7	5.3		34.2	63.4		1.3
LSD (.05)		2459	13.8	1.9	0.7		11.4	15.6		1.6
CV (%)		34	29.9	12.6	9.3		73.3	48.6		41.3

[†]Sugar yield = root yield × % sugar.

[‡]Percent of fresh weight.

[§]0 = no visual evidence of disease, 5 = classical symptoms of rhizomania, 9 = dead.

[¶]% resistant roots; %R (0–3) = [(total number roots in DI classes 0 + 1 + 2 +3) ÷ total roots harvested] × 100; %R (0–4) = [(total number roots in DI classes 0 + 1 + 2 + 3 + 4) ÷ total roots harvested] × 100; and %R (0–5) = (total number roots in DI classes 0 + 1 + 2 + 3 + 4 + 5) ÷ total harvested] × 100.

[#]Rhizomania canopy scores (associated with rhizomania severity) were taken just before harvest; 1 = dark green, 2 = green, 3 = light green, 4 = mostly yellow, 5 = 100% uniformly yellow.

[††]0 = very dark green with no yellowish plants to 9 = 100% of the plants showing yellowishness typical of rhizomania susceptible varieties. Usually there is a strong association between yellowishness and susceptibility to rhizomania.

[‡‡]1-row plots, 6.7 m, RCBD, 8 replications, planted 5 May 2006, harvested 3 Oct. 2006.

[§§]*Rz1* and *Rz2* are the two most commonly deployed dominant resistance genes to protect against rhizomania.

[¶¶]1-row plots, 3.3m, RCBD, 6 replications planted 5 May 2006, harvested 20 Nov. 2006.

[##]Experimental hybrids of FC1018 (05-FC1018), FC1019 (05-FC1019), and FC1022 (05-FC1022) test crossed to monogerm, *rzrz* tester C790–15CMS.

[†††]1-row plots, 2.7 m, RCBD, 4 replications, planted 12 May 2008, harvested 14 Nov. 2008.

[‡‡‡]1-row plots, 2.7 m, RCBD, 6 replications, planted 12 May 2008, harvested 6 Nov. 2008.

than FC1019 and FC1022. The CLS rating for FC1020 was intermediate, with significantly higher resistance than the susceptible check but with significantly more disease than the tolerant check (Table 2). FC1019 and FC1022 had more CLS than FC1018, although all of these germplasms had higher resistance to CLS than the Betaseed susceptible check (Table 2). Overall, FC1018 and FC1020 have a moderate tolerance to CLS, whereas FC1019 and FC1022 are moderately susceptible.

Curly Top

C391 and FC607, which were used as parents in this cross, are known to have moderate resistance to curly top; however, no selection was made for resistance. All of the germplasms were tested at the curly top nursery of the Beet Sugar Development Foundation (Denver, CO) at Kimberly, ID (Panella et al., 2008). The curly top nursery at Kimberly, ID was planted late (early June) to maximize the number of viruliferous leafhoppers available for transfer of the virus to plants in the 8- to 10-leaf stages. Plots were 4 m long and two-rowed with 56 cm between rows and 25–30 cm within-row spacing replicated two times. Viruliferous beet leafhoppers were released mid-July. The field was sprayed 1–2 wk later (Thiodan EC) to kill the leafhoppers. Plots were visually evaluated and rated on a DI scale of 0 (no symptoms) to 9 (dead). The most important rating is the final rating, in which the expression of the disease is at its peak (Mumford, 1974). The nursery was planted in a completely randomized block design. The data were analyzed by PROC GLM (SAS Institute, Cary, NC) by date. The differences among the lines at all three dates were significant ($P < 0.05$).

In 2006 and 2008, FC1019 performed significantly better than the susceptible check but was not different from the resistant check (Table 3). FC1018 was significantly better than the susceptible check in 2006 but not in 2008. In 2006, FC1022 was significantly better than the susceptible check and not significantly different from the resistant control. In 2008, FC1022 was not significantly different from the susceptible control in one experiment but was in the other (Table 3). FC1020 was intermediate in 2008—not significantly better than the susceptible check but not significantly different from the resistant check in one test and significantly more susceptible

Table 2. USDA entries FC1018 (05-FC1018), FC1019 (05-FC1019), FC1022 (05-FC1022), and FC1020 (07-FC1020) in the Betaseed (Shakopee, MN) Cercospora leaf spot nursery at Rosemount, MN in 2006 and 2008.

		2006		2008	
Variety	Description	Last reading†	Mean	Last reading	Mean
		1–9‡			
05-FC1018	20031018 RZM-CR-%	7.0	4.5	3.3	2.3
05-FC1019	20031019 RZM-CR-%	7.7	5.2	5.3	4.0
05-FC1022	20031022 RZM-CR-%	7.7	5.1	5.0	3.8
07-FC1020	05-FC1022, 1018, 1019			4.3	3.3
USDA-ARS	FC715CMS			2.3	1.6
USDA-ARS	Tolerant check			2.3	1.9
Betaseed	Tolerant nonhybrid check			2.7	1.9
Betaseed	Mod tolerant nonhybrid check			3.0	2.2
USDA-ARS	Susceptible check			6.7	5.0
Betaseed	Susceptible nonhybrid check			6.0	4.2
Beta 4430R	Betaseed	8.6	6.4		
Betaseed	Susceptible check	9.1	6.6		
Betaseed	Moderately susceptible check 1	8.6	6.0		
Betaseed	Moderately susceptible check 2	8.0	6.1		
EL-SP22–0	(EL-SP7322–0) Tolerant check	5.9	3.8		
Betaseed	Tolerant check	4.5	3.0		
$LSD_{(.05)}$		0.8	0.5	1.0	
CV (%)		8.0	7.5	14.1	

†The last reading is the most severe of the epiphytotic.

‡A visual score based on the KWS rating system: 1 = absence of leaf spot spots; 9 = leaves entirely necrotic.

Table 3. Disease index (DI) ratings for FC1018 (05-FC1018), FC1019 (05-FC1019), FC1022 (05-FC1022), and FC1020 (07-FC1020), the experimental hybrids of FC1018, FC1019, and FC1022, and the checks during and after development in the Beet Sugar Development Foundation's beet curly top nursery near Kimberly, ID.

		Last DI rating†‡			
Variety	Description	11 Sept. 2006		23 July 2008	
		1–9§			
05-FC1018	RZM-CR-% 20031018	5.7	5.3	6.8	7.0
05-FC1019	RZM-CR-% 20031019	5.0	6.0	5.5	5.8
05-FC1022	RZM-CR-% 20031022	5.7	6.3	6.2	5.3
05-FC1018H50	C790–15CMS × 05-FC1018	4.7	5.7		5.3
05-FC1019H50	C790–15CMS × 05-FC1019	4.7	5.0		5.0
05-FC1022H50	C790–15CMS × 05-FC1022	5.0	5.7		5.5
07-FC1020	05-FC1018, 1019, 1022			6.0	6.0
HM-PM21	Resistant check	4.0		5.5	
US H11	Resistant check	4.3			
03-, 04, 05-C37	Resistant check, Inc. C37	4.7		5.3	
Beta G6040	Resistant check		4.7		4.8
HM-E17	Susceptible check	7.3			
Monohikari	Susceptible check	8.7		6.8	
19821052	Susceptible check		9.0		
20011011H	Susceptible check				7.3
$LSD_{(0.5)}$		1.0	1.3	1.0	0.9
CV		12.6	13.0	10.2	9.7

†Last rating (most severe) is most important indicator of resistance of the germplasm being screened.

‡The germplasms and their experimental hybrids were tested in two different experiments in 2006 and 2008.

§Rating was visual; 1 = no symptoms, 9 = dead.

Table 4. USDA entries FC1018 (05-FC1018), FC1019 (05-FC1019), FC1022 (05-FC1022), and FC1020 (07-FC1020) in the Betaseed Aphanomyces root rot nurseries at Shakopee, MN in 2006 and 2008.

		2006		2008			
Variety	Description	Second reading	Mean†	Second reading	Mean	Second reading	Mean
		1–9‡					
05-FC1018	20031018 RZM-CR-%	4.0	3.8	2.0	1.8		
05-FC1019	20031019 RZM-CR-%	3.3	3.6	2.7	2.2		
05-FC1022	20031022 RZM-CR-%	4.7	4.7	3.0	2.8		
07-FC1020	05-FC1022, 1018, 1019			2.3	2.2	2.7	2.6
Tolerant check 1	Betaseed	1.5	1.9				
Tolerant check	Betaseed	2.0	2.4				
Susceptible check	Betaseed	6.7	6.1				
Susceptible check	Betaseed	6.0	5.3				
Hybrid tolerant check	Monohikari	3.7	3.7				
Tolerant check	EL-SP7322–0	1.2	1.6				
Tolerant check	Betaseed			2.0	1.7	1.9	1.5
Susceptible check	Betaseed			5.3	4.3	5.3	4.3
$LSD_{(0.05)}$		1.5	1.3	0.9	0.9	1.1	0.9
CV		25.7	23.2	20.0	25.4	26.0	25.4

†Means are of two readings, but the second, more severe, rating is the most meaningful.

‡Rating was visual and was based on stand and plant health; 1 = complete stand of healthy beets, and 9 = no surviving plants.

than the resistant control in the other (Table 3). Hybrids of FC1018, FC1019, and FC1022 with C790–15CMS performed well in the 2008 test (Table 3). FC1019 showed resistance to beet curly top, and the other germplasms (FC1018, FC1022, and FC1020) showed a moderate tolerance to this disease.

Aphanomyces Root Rot (Aphanomyces Black Root)

The germplasms were evaluated for resistance to Aphanomyces root rot (caused by *Aphanomyces cochlioides* Drechsl.) in a field nursery near Shakopee, MN by Betaseed. All plots were two rows and 3 m long with 56-cm row spacing. The seed was treated with standard rates of Allegiance and Thiram. The trials were planted in warm soils between late May and early June to facilitate pathogen development. The plots were thinned to a uniform stand of 8–9 cm between plants. Irrigation was used as needed to provide adequate moisture for initial stand establishment and to maintain conditions favorable for *A. cochlioides*. Fungicides were applied as needed to control Rhizoctonia root rot and CLS. A visual scale of 1–9 based on stand persistence and plant health was used to evaluate Aphanomyces root rot damage. A rating of 1 indicates a complete stand of healthy beets, and a rating of 9 indicates no surviving plants. Ratings were taken one to three times during the growing season. Experimental design was a randomized complete block with three replications (M. Rekoske, personal communication, 2006; J. Miller, personal communication, 2008).

In the more severe aphanomyces evaluation of 2006, at the second reading, both FC1018 and FC1019 were significantly more resistant than both susceptible checks, and FC1022 was significantly more resistant than one of the susceptible checks but not the other (Table 4). In 2008, which included all four germplasms, all were significantly more resistant better than the susceptible check. All were not significantly less resistant than the tolerant check except for FC1022, which did not perform as well as the tolerant check. In the second trial in 2008, where only FC1020 was tested, it performed consistently with the first trial. In general, FC1018, FC109, and FC1020 had moderate tolerance and FC1022 had moderate susceptibility to *A. cochlioides*.

Rhizoctonia Root and Crown Rot

The germplasms were tested for resistance to Rhizoctonia root and crown rot at Fort Collins after selection at Salinas (Table 5) (Panella et al., 2008). The DI was determined by visually rating each root in a single-row (4 m) plot on a scale of 0 (disease free) to 7 (dead and rotted). Plot means for each of the five replications were used for an ANOVA (PROC MIXED or GLM, SAS), and the LSD means separation with a $P = 0.05$ was also used.

In 3 yr of testing, FC1018 was not significantly different from the highly resistant control and was significantly more resistant than the susceptible control (Table 5). In 2 of 3 yr of testing, FC1019 was significantly more resistant than the susceptible check, and in 2 of 3 yr it was not significantly more susceptible than the resistant checks. In the 2007 test, it was not significantly different from the susceptible check (Table 5). In 2 yr of testing, FC1020 was not significantly different from the resistant control and was significantly more resistant than the susceptible control (Table 5). In 3 yr of testing, FC1022 was scored more resistant, but not significantly, than the susceptible check. Thus, FC1018 had excellent resistance to Rhizoctonia root rot, FC1019 FC1020 had moderate resistance, and FC1022 was moderately susceptible.

Field Performance and Sugar Yield

FC1018, FC1019, and FC1022 have shown favorable yield characteristics when evaluated as lines and as pollinators in experimental hybrids in two trials grown in fields infested with rhizomania (1906, 3106) at Salinas in 2006 (Table 1). They had a significantly higher sugar yield than the susceptible check ('Roberta', *rzrz*), and the sucrose concentration was not significantly different than that of Beta 4430R (an *Rz1* check) (Table 1). In both trials, FC1022 and FC1019 outperformed FC1018 in sugar yield: FC1022 because of a high sucrose concentration, and FC1019 because of a high root yield. In general, hybrids outperform lines in yield because of the heterosis achieved in the hybrid. In the two 2008 trials (1208, 1908, Table 1), FC1020 had a significantly higher sugar yield than the susceptible check and was not

significantly different from Beta 4430R. In one of these tests (1908), FC1020 had a sucrose concentration that was not significantly different than that of Beta 4430R, and in the other test (1208), the sucrose content of FC1020 was not significantly different from any of the controls.

Table 5. Rhizoctonia root and crown rot resistance evaluations in Fort Collins, CO of FC1018 (05-FC1018), FC1019 (05-FC1019), FC1022 (05-FC1022) and FC1020 (08-FC1020/07-FC1020 in 2009 6R) and checks. Given here are the disease index, the percentage of healthy plants and the percentage of harvestable plants.

	2007 (6R)			2006 (5R)		
Description	DI	Healthy†	Harvestable‡	DI	Healthy	Harvestable
	0–7§	%		0–7	%	
05-FC1018	1.8	48.3	76.7	2.5	29.7	63.2
05-FC1019	3.1	29.9	49.6	3.0	20.1	56.4
05-FC1022	3.2	26.1	52.2	4.2	13.0	33.2
FC901/C817 (susceptible check)	3.5	25.2	53.0	4.2	11.7	31.9
FC703 (resistant check)	2.3	41.0	62.3	2.2	32.8	72.4
FC705/1(highly resistant check)	1.7	47.8	80.5	1.8	30.8	85.9
Experiment mean	2.9	34.3	57.0	3.5	19.5	48.3
$LSD_{0.05}$	1.5	24.3	27.0	1.2	19.5	20.1
CV	40.2	56.9	37.9			
	2008 (7R)			2009 (6R)		
Description	DI	Healthy	Harvestable	DI	Healthy	Harvestable
	0–7	%		0–7	%	
05-FC1018	2.5	0.0	57.9			
05-FC1019	3.0	0.0	43.0			
05-FC1022	3.4	0.0	28.8			
07-FC1020	2.8	0.0	45.4	3.9	12.7	39.4
08-FC1020				3.7	10.1	41.5
FC901/C817 (susceptible check)	4.3	0.0	24.5	5.0	3.9	8.3
FC703 (resistant check)	2.3	0.0	58.7	3.0	17.5	51.7
FC705/1(highly resistant check)	2.2	0.0	79.8	2.1	37.1	75.7
Experiment mean	3.4	0.9	36.8	5.4	3.8	14.0
$LSD_{0.05}$	0.95	NS	19.1	0.9	9.4	16.7
CV	22.7		41.7	13.3	198	96

†Percentage of healthy roots (disease index categories 0 and 1 combined). Percentages were transformed to arcsin-square roots to normalize the data for analyzes.

‡Percentage of diseased roots likely to be taken for processing (disease index categories 0–3 combined). Percentages were transformed to arcsin-square roots to normalize the data for analyzes.

§0 = healthy, 7 = dead.

Availability

Breeder seed of FC1018, FC1019, FC1022, and FC1020 is maintained by the USDA-ARS and will be provided in quantities sufficient for reproduction on written request to Sugarbeet Research, USDA-ARS, Crops Research Laboratory, 1701 Center Ave., Fort Collins, CO 80526–2083. Seed of these releases has been deposited in the National Plant Germplasm System, where it will be available for research purposes, including development and commercialization of new cultivars. We request that appropriate recognition be made of the source when this germplasm contributes to a new cultivar. U.S. Plant Variety Protection will not be requested for FC1018, FC1019, FC1022, and FC1020.

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