Registration of FC1028, FC1037, FC1038, and FC1036 Multigerm Sugarbeet Germplasm with Multiple Disease Resistances

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ABSTRACT

FC1028 (Reg. No. GP-282, PI 665053), FC1036 (Reg. No. GP-283, PI 665054), FC1037 (Reg. No. GP-284, PI 665055), and FC1038 (Reg. No. GP-285, PI 665056) sugarbeet (*Beta vulgaris* L.) germplasms were released and developed by the USDA-ARS, at Fort Collins, CO, Salinas, CA, and East Lansing, MI, in cooperation with the Beet Sugar Development Foundation, Denver, CO. All four germplasms are diploid, multigerm sugarbeet populations in normal cytoplasm, segregating for self-sterility (*Sf:SsSs*), multigermity (*M:mm*), hypocotyl color (*R:rr*) and the gene (*Rz1:rz1rz1)*, which confers resistance to some strains of rhizomania.

FC1028 (Reg. No. GP-282, PI 665053), FC1036 (Reg. No. GP-283, PI 665054), FC1037 (Reg. No. GP-284, PI 665055), and FC1038 (Reg No. GP-285, PI 665056) differ in their resistance to Cercospora leaf spot (CLS; caused by *Cercospora beticola* Sacc.). They also all exhibited resistance to Aphanomyces root rot (caused by *Aphanomyces cochlioides* Drechsl.). All of the germplasms except FC1036 were moderately tolerant of *Beet curly top virus* (BCTV). Both FC1037 and FC1038 demonstrated resistance to root-rotting strains (AG-2-2) of *Rhizoctonia solani* Kühn, with FC1037 performing better than FC1038. These populations provide sources from which to select disease-resistant, multigerm pollinator parents. Because monogerm and O-type is within their parentage, it should be possible to select monogerm, O-type, and cytoplasmic male sterility (CMS) maintainer lines from these germplasms as well.

In the United States, sugarbeet is grown from the Imperial Valley of California to Michigan in the Great Lakes Region with production in 12 states, and diseases may have an enormous impact on production (Harveson et al., 2009). Cercospora leaf spot is one of the most widespread diseases of sugarbeet worldwide and is a serious problem in many U.S. production areas (Weiland and Koch, 2004; Jacobsen and Franc, 2009). It has been estimated that a severe epidemic can cause up to a 42% loss of gross sugar or up to a 43% revenue loss (Smith and Ruppel, 1973; Smith and Martin, 1978; Shane and Teng, 1992). The disease damages the leaves, which, consequently, reduces root yield, the percentage of sucrose, and the purity of the extracted juice (Jacobsen and Franc, 2009).

Cercospora leaf spot is managed by combining spraying with commercial fungicides and the use of disease-tolerant germplasm (Miller et al., 1994; Secor et al., 2010). Even with the most resistant hybrids, fungicide applications are economical in areas where the disease is severe almost every year, such as the Red River Valley in the United States or southern Europe (Miller et al., 1994; Ioannidis and Karaoglanidis, 2010; Secor et al., 2010). The occurrence of *C. beticola* strains that are resistant or increasingly tolerant to our most effective fungicides is evident (Davidson et al., 2006; Hanson, 2010; Bolton et al., 2012). Additionally, some of these fungicides may be removed from the market because of their perceived or real threat to the environment and the proclivity of *C. beticola* to develop fungicide tolerance. The development of Cercospora leaf spot–resistant sugarbeet lines and hybrids with greater levels of host-plant resistance offers a more sustainable solution to this disease problem.

Resistance to CLS long has been a goal of the USDA-ARS sugarbeet breeding programs (Panella and McGrath, 2010).

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Abbreviations: BCTV, *Beet curly top virus;* BNYVV, *Beet necrotic yellow vein virus*; BSDF, Beet Sugar Development Foundation; CLS, Cercospora leaf spot; CMS, cytoplasmic male sterility; RB-BNYVV, resistance (*Rz1* mediated)–breaking strains of BNYVV; SR, smooth root.

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The large environmental variation and low heritability of resistance has made it difficult to enhance resistance through mass selection; therefore family selection has been practiced, and loss of vigor due to continued inbreeding has been noted (McFarlane, 1971; Panella, 1998). Incorporation of high levels of leaf spot resistance into varieties with superior agronomic performance also is difficult (Smith and Campbell, 1996). These germplasm releases are an effort to broaden the genetic base of current CLS-resistant sugarbeet germplasm by combining sources from three public breeding programs.

Methods

Early-Generation Population Development

The original parental lines were CLS-resistant germplasm from USDA-ARS sugarbeet enhancement programs in East Lansing, MI; Salinas, CA; and Fort Collins, CO. Eight germplasms from the East Lansing program were used: EL50, EL52, SR96, 99J25-023, 98J02x05, 99J02-00, 99J31-00, and 99J9-00 (Saunders et al., 1999, 2003; McGrath, 2003). Four germplasms came from the Fort Collins program: FC 607, FC 708, FC 709-2, and FC 715. (Smith and Ruppel, 1980; Hecker and Ruppel, 1981; Ruppel et al., 1995; Panella, 1999). There were three germplasms from the Salinas program: 9933, CR10, and CR11 (Lewellen, 2002, 2006)

East Lansing Germplasm

EL50 (PI 598073) is a heterogeneous, monogerm germplasm selected for high sugar yield per hectare and CLS resistance (Saunders et al., 1999). EL52 (PI 628274) was selected for resistance to Rhizoctonia root rot, CLS, and a smooth root (SR) conformation (Saunders et al., 2003). SR96 (PI 628272) was selected for its increased sucrose percentage and CLS resistance in a well-expressed SR phenotype (McGrath, 2003).

Germplasm 99J25-023 is a blend of several monogerm, half-sib families related to EL52 and selected for SR (Saunders et al., 2003). Germplasm 98J02x05 resulted from a full-sib cross of two SR plants (one mono- and the other multigerm) from the same family, having 50% of the genetic background from EL50 (Saunders et al., 1999). The germplasm is self-sterile, segregates for O-type (CMS maintainer line), and was selected for high tonnage and sucrose percentage. Germplasm 99J02-00 consists of monogerm selections from an F_2–derived from pair cross (full-sib cross) of the monogerm SR parent of 98J02x05 and a monogerm O-type plant derived from EL52 (Saunders et al., 2003). Germplasm 99J31-00 was selected for monogerm and SR, is self-sterile and segregates for hypocotyl color. Germplasm 99J19-00 is monogerm, very SR, and self-sterile. All of the above lines performed well in the 1999 artificially inoculated CLS screening nursery at Fort Collins.

Fort Collins Germplasm

FC 607 (PI 590837) is a relatively inbred, monogerm, O-type line that combines resistance to both CLS and BCTV (Smith and Ruppel, 1980). FC 708 (PI 590845) is a self-fertile, monogerm, O-type germplasm that is highly resistant to Rhizoctonia root rot and moderately resistant to CLS (Hecker and Ruppel, 1981). FC 715 (PI 574625) is a monogerm, O-type, pseudo-self-fertile (*SsSs*) sugarbeet germplasm resistant to Rhizoctonia root rot, moderately tolerant to CLS, and has low to medium resistance to BCTV (Ruppel et al., 1995). FC 709-2 (PI 599668) is a multigerm, non-O-type, pseudo-self-fertile germplasm with excellent resistance to Rhizoctonia root rot and moderate resistance to CLS and sugarbeet root aphid (*Pemphigus betae* Doane) (Panella, 1999).

Salinas Germplasm

Germplasm 9933 (PI 652891) segregates for the *Rz1* gene, which confers resistance to rhizomania (caused by *Beet necrotic yellow vein virus*; BNYVV) but does not carry the *Rz2* gene, which confers resistance to strains of BNYVV that have overcome *Rz1* (RB-BNYVV) (Liu et al., 2005). It also carries moderate resistance to BCTV and virus yellows (caused by *Beet chlorotic yellow virus*). This germplasm is multigerm and self-fertile and segregates for genetic male sterility. It was derived from composite crosses among Salinas breeding populations, germplasms, and archaic hybrids developed in Colorado by both ARS and private companies in an attempt to combine resistances to rhizomania, CLS, Aphanomyces root rot, root aphid, BCTV, and virus yellows.

CR10 (derived from PI 593692) and CR11 (PI 636343) were developed in the ARS breeding program at Salinas, CA (Lewellen, 2006). CR10 is a narrowly based germplasm derived from S_1 and half-sib selections that segregated for high sucrose and resistance to CLS and rhizomania. The source of CLS resistance was from germplasm developed at Rovigo, Italy (Istituto Sperimentale per le Colture Industriali). The Rovigo line was crossed with male sterile (*aa*) Salinas germplasm 9911, which is similar to population C931 (PI 636340; Lewellen, 2006). CR11 comes from the same sources as CR09 but is a more broadly based composite of germplasm and backcrosses resistant to CLS and rhizomania (Lewellen, 2002).

Development of 20021028, 20021037, and 20021038 at Fort Collins

Breeding material in the USDA-ARS program at Fort Collins was increased either in the field in a mother root nursery or in the greenhouse (Panella et al., 2008). A cross based on hypocotyl color (Panella et al., 2008) was made between FC 709-2 (*R_*) (PI 599668) and 9933 (*rr*) (Panella, 1999). Eight FC709-2 plants provided pollen to nine plants of 9933 (*rr*), producing 20011014H2. One hundred thirty-four plants (red hypocotyl) of 20021024H2 were bulk increased to produce 20021028.

Polycrosses were made among roots harvested in 1999 from a CLS screening nursery that had been artificially inoculated (Panella et al., 2008). The polycrosses were made with hypocotyl color as a marker, and in the first polycross, East Lansing germplasm was used as the pollen parent (red hypocotyl). There were 287 pollen-producing plants from the eight germplasms: EL50 (30 plants), EL52 (40), 99J25-023 (40), 98J02x05 (40), 99J02-00 (40), 99J31-00 (25), SR96 (40), and 99J9-00 (32); which pollinated 34 plants (green hypocotyl) of FC 607 (15) and FC 709-2 (19). These were

harvested as 20001014H2 and 20001014H4 off of FC 607 and FC 709-2, respectively.

In the second polycross, 107 Fort Collins germplasms provided pollen: FC 607 (19), FC 708 (38), FC 709-2 (4), and FC 715 (46). These pollinated 51 East Lansing plants: 99J25-023 (9), 99J02-00 (4), 98J02x05 and 99J31-00 (8), EL52 and SR 96 (20), EL50 and 99J9-00 (10). These were harvested as 2001015H2; 20001015H4; 20001015H5 and 20001015H3; 20001015H6 and 20001015H9; and 20001015H7 and 20001015H8, respectively. (In three instances, seed stalks from 2 germplasms were inadvertently bulked.)

The hybrid seed (red hypocotyl seedlings) from these polycrosses was bulk increased with the following number of plants contributing from these seed productions: 20001014H2 (75 plants); 20001014H4 (75); 2001015H2 (25); 20001015H4 (25); 20001015H5 and 20001015H3 (25); 20001015H6 and 20001015H9 (40); and 20001015H7 and 20001015H8 (40). In this increase, 278 of 305 mother roots were harvested, resulting in seed production 20011001. Pollen parent 20011001 (*A_*) (173 plants) was crossed to 68 male-sterile (*aa*) plants of CR011 producing 20021001H2, and to 46 male sterile (*aa*) plants of CR10 producing 20021001H3. 20021001H2 was bulk increased (153 plants) to produce 20021037, and 20021001H3 was bulk increased (145 plants) to produce 20021038. Seed of 20021028 (96 g), 20021037 (96 g), and 20021038 (192 g) was sent to Salinas to screen and select for rhizomania resistance and other traits.

Final Population Development and Selection at Salinas

Development of 04-FC1028, 04-FC1037, 04-FC1038, and 09-FC1036

04-FC1028 was produced by one cycle of mass selection from FC20021028. In April 2003, approximately 400 plants of FC20021028 were established at 20-cm spacing under rhizomania conditions at Salinas. Seven-month-old plants were selected based on their resistance to rhizomania, root size, and root conformation. Field-selected beets were analyzed for sucrose concentration and reselected. Seed was produced in spring of 2004 in bulk from 37 mother roots (~9%) that would have segregated fertile and genetic male sterile (*aa*) plants. 04-FC1037 was produced by one cycle of mass selection from FC20021037, which was performed in a parallel program as FC20021028 above. Seed was produced from 46 mother roots (~12% selection). 04-FC1038 was produced by one cycle of mass selection from FC20021038, which was performed in a parallel program as FC20021028 above. Seed was produced from 45 mother roots (~11% selection).

The population called FC1036 (syn-1) was created in 2005 by combining lines 04-FC1028, 04-FC1037, and 04-FC1038. Stecklings of these three component lines were grown in an August-planted steckling nursery under rhizomania conditions. In early December 2004, 3-mo-old stecklings were harvested based on absence of symptoms from rhizomania, size, and root conformation and placed under photo-thermal induction for 4 mo to induce flowering (Panella et al., 2008). In early April, 51, 65, and 66 stecklings of 04-FC1028, 04-FC1037, and 04-FC1038, respectively, were mixed and planted in one spatially isolated seed plot. After natural pollination occurred between the genetic male sterile (*aa*) plants and the fertile ones, seed was harvested from only the male sterile plants (58 plants) and bulked in June 2005 as 05-FC1036. Seed from this plot should represent recombination in essentially all combinations among the three components and bring together disease resistances from Fort Collins (Rhizoctonia and CLS), East Lansing (CLS and Aphanomyces), and Salinas (rhizomania, BCTV, virus yellows, and CLS) breeding programs.

Seed of 05-FC1036 was planted May 5, 2006 in a trial field area with a history of rhizomania. Approximately 1200 equally spaced (20 cm apart) plants were established. In adjacent susceptible check varieties, rhizomania developed to moderate severity. Most plants of 05-FC1036 appeared to have resistance (*Rz1*) and grew well. In late July, powdery mildew (caused by *Erysiphe polygoni* D.C.) occurred from natural infection and was not controlled. On July 18, 2006, the plants were inoculated with mixed strains of *Cercospora beticola* from ground, dried sugarbeet leaves saved from 2005 and mixed with talc. A moderate level of leaf spot had developed by August 18 and was not controlled through the remainder of the season. On July 28, 2006, each plant was wound inoculated with mixed strains of *Pectobacterium betavasculorum* (Thomson et al.) Gardan et al. [syn. *Erwinia carotovora* (Jones) Bergey et al. subsp. *betavasculorum* Thomson et al.] that had been grown in liquid media. In late August it was observed that about 5% of the individual plants were naturally infected with *Sclerotium rolfsii*.

The 6-mo-old plants were mass selected based on the least symptomatic expression of any disease. Plants with visible root rot and susceptibility to rhizomania were discarded. Roots that fit in a general category of moderately resistant to powdery mildew and CLS were potential candidates for selection. Field selection among this group was based on root size, shape, and conformation. About 200 roots (16.7%) were harvested and analyzed for sugar concentration. Based on the final criteria of sucrose concentration and yield (root weight × % sucrose), 37 roots (3%) were selected for seed production of which 36 were harvested in bulk to produce 07-FC1036 (syn-2) seed. The goal was to select, either directly or indirectly based on sugar production, for improved resistance or frequency of resistance to rhizomania, *P. betavasculorum*, powdery mildew, and CLS.

In 2008, 41 unselected stecklings from 07-FC1036 were grown in an isolation chamber and increased as 08-FC1036 (syn-3). Seed of 08-FC1036 was harvested and bulked from all plants, both fertile (*A_*) and sterile (*aa*). In 2009, 42 unselected stecklings from 08-FC1036 were grown in an isolation chamber and increased. Seed of 09-FC1036 (syn-4) was harvested and bulked from all plants, both fertile (*A_*) and sterile (*aa*).

For both 09-FC1036 and 08-FC1036, there would have been the possibility for both self-pollination and sib-mating among the individual plants; therefore, several generations and cycles of recombination are possible, including syn-1 through syn-4 and S_0 through S_3. The variability among the progeny of 09-FC1036 may be considerable due to differential inbreeding.

For the increase of this line, a cycle of recombination through the male sterile plants (*aa*) is recommended.

Characteristics

Agronomic and Morphological Description

FC1028, FC1036, FC1037, and FC1038 have fertile cytoplasm. They are predominately multigerm but segregate for the monogerm seed ball trait: FC1028, 17% monogerm; FC1036, 10% monogerm; FC1037, 16% monogerm; and FC1038, 12% monogerm. All of the populations 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). All germplasms segregate for genetic male sterility (*aa*) and self-sterility (S^s) because self-fertility was introduced through the Salinas germplasms 9333, CR010, and CR011. All the populations except for FC1028 also should segregate for the SR trait introduced from the East Lansing germplasms (Theurer, 1993). All the populations segregate for hypocotyl color. When tested for germination, FC1028 had 62, FC1036 (09-FC1036) had 83, FC1037 had 116, and FC1038 had 69 sprouts per 100 seedballs. 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 and Yield

FC1028 (04-FC1028), FC1037 (04-FC1037), FC1038 (04-FC1038), and their experimental hybrids with C833-5HO were evaluated in 2005 for yield under conditions of rhizomania (Table 1). FC1037 and FC1038 were not significantly different from the *Rz1* check (Beta 4430R) in sugar yield, root yield, or percentage sugar. FC1028 had lower, but not significantly, root yield and percentage sugar, which gave it a significantly lower sugar yield than Beta 4430R. The hybrids did not perform as well as the check variety in the absence of rhizomania (test 1105, Table 1) but were comparable to the checks in the field infested with rhizomania (test 4605, Table 1). FC1036 (07-FC1036) was tested in 2008 for yield in Salinas, CA in fields infested with rhizomania. When tested in a field infested with normal BNYVV strains and the resistance-breaking strains (RB-BNYVV, i.e., able to overcome the *Rz1* resistance gene), FC1036 was not significantly different from the commercial hybrid check carrying the *Rz1* gene, although it had higher sugar yield, root yield, and percentage sugar. When tested in a field infested with the normal strains of rhizomania, root yield was significantly better than that of the susceptible commercial hybrid check but significantly lower than for the *Rz1* commercial hybrid check. When different measures of rhizomania resistance are considered (Table 1), FC1036 was significantly better than the susceptible check and not significantly different from the *Rz1* (rhizomania resistant) hybrid check, 'Beta 4430R'.

Cercospora Leaf Spot

The germplasms were evaluated by Betaseed, Inc. personnel in a field nursery for resistance to CLS at Rosemount, MN, during and after selection for resistance for rhizomania (Table 2). All plots comprised two rows that were 3 m long with 56 cm row spacing. The seed was treated with Allegiance (Bayer), Thiram (Bayer), and Tachigaren (Sankyo Agro Co. Ltd.). 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 the development of CLS. 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 leaves that are entirely necrotic. Ratings were taken each week during the period of infection. The experimental design was either a randomized complete block with three replications (2006, 2007) or a 9 by 9 lattice with three replications (2008) (M. Rekoske and J. Miller, personal communication, 2008).

In all 3 yr of testing, FC1028 (04-FC1028), FC1037 (04-FC1037), FC1038 (04-FC1038), and FC1036 (05-, 06-, and 07-FC1036) had moderate levels of resistance that were significantly better than the susceptible check and significantly lower (higher scores) than the resistant checks (Table 2). This was true in 2008, when the disease pressure was low, and in 2006, when the disease pressure was very high.

Beet Curly Top

Beet curly top disease is caused by Curtoviruses, a group of viruses transmitted by the beet leafhopper [*Circulifer tenellus* (Baker)] (Strausbaugh et al., 2008). Some of the Fort Collins and Salinas germplasm used in this cross had been bred for resistance to BCTV; however, no selection was made for resistance (Panella, 1998; Panella and Strausbaugh, 2010). All of the germplasms were tested at the joint ARS–Beet Sugar Development Foundation (BSDF) curly top nursery at Kimberly, ID as previously described (Panella et al., 2008). The plots were visually evaluated and rated on a disease index scale of 0 (no symptoms) to 9 (dead). The most important rating is the final rating, in which the disease expression is at its peak (Mumford, 1974). The nursery was planted in a completely randomized block design. Data were analyzed by PROC GLM (SAS Institute, Cary, NC) in 2006 and 2008 by date. (In 2005, the design was not randomized and a statistical analysis would not be appropriate.) Differences among lines at the final rating in 2006 and 2008 were significant ($P < 0.05$). The trials in 2005 and 2008 had three replications in two-row plots that were 4 m long.

In 2006 and 2008, FC1028 (04-FC1028), FC1037 (04-FC1037), FC1038 (04-FC1038), FC1036 (06-FC1036), and FC1036 hybrids were significantly more tolerant than the susceptible check and less tolerant than the resistant check (Table 3) to beet curly top. Two other increases of FC1036 (05-FC1036 and 07-FC1036) were not significantly different from the susceptible check. All of these germplasm have

Table 1. Sugar yield, root yield, and sucrose content of FC1028 (04-FC1028), FC1036 (05-, 06-, 07-FC1036), FC1037 (04-FC1037), and FC1038 (04-FC1038), their experimental hybrids (FC1028, FC1037, and FC1038), and checks when in fields infested with rhizomania, caused by *Beet necrotic yellow vein virus* (BNYVV) alone or a combination of BNYVV and RB-BNYVV (resistance-breaking strains of BNYVV), in Salinas, CA in 2005 and 2008.

					Rhizomania resistance				
					Disease	DI rating			
Variety	Description	Sugar yield[†]	Root yield	Sugar	index (DI)	0–4	0–5	Canopy	Yellowing
		kg ha^{-1}	Mg ha^{-1}	% fresh wt.	0–9[‡]	%R[§]		1–5[¶]	0–9[#]
Test 4105[‡‡]									
04-FC1028	FC1028	6636	42.07	15.79				1.8	
04-FC1037	FC1037	7795	47.44	16.42				1.8	
05-FC1038	FC1038	8440	52.51	16.13				2.0	
Beta 4430R	*Rz1*[§§] check	7909	48.79	16.30				2.0	
Roberta	*rzrz* check	5257	35.73	14.71				3.1	
Angelina	*Rz1* + *Rz2* check	10706	62.88	17.05				1.5	
$LSD_{0.05}$		1246.6	7.57	0.53				0.6	
CV		15.2	15.06	3.27				34.1	
Test 1105[¶¶]									
04-FC1028H5[##]	C833-5HO × 04-1028	14949	87.00	17.17					
04-FC1037H5	C833-5HO × 04-1037	14861	87.09	17.09					
04-FC1038H5	C833-5HO × 04-1038	13705	79.99	17.15					
Beta 4001R	Betaseed	16313	94.82	17.21					
Beta 4430R	Betaseed	16941	100.22	16.86					
$LSD_{0.05}$		1412.5	7.8	0.56					
CV		9.4	8.8	3.34					
Test 4605[†††]									
04-FC1028H5	C833-5HO × 04-1028	10156	60.10	16.88					
04-FC1037H5	C833-5HO × 04-1037	10683	63.30	16.86					
04-FC1038H5	C833-5HO × 04-1038	10984	64.89	16.94					
Beta 4001R	Betaseed	12242	71.64	17.10					
Beta 4430R	Betaseed	9481	55.04	17.25					
$LSD_{0.05}$		1192.6	6.9	0.46					
CV		11.9	11.45	11.9					
Test 1208[‡‡‡]									
07-FC1036	05-FC1036, (CR)	5805	37.43	15.2	7.65	6.4	15.0		4.9
Beta 4430R	*Rz1* check	3994	28.83	13.3	7.7	4.4	12.8		5.2
Roberta	*rzrz* check	3974	31.32	12.7	8.3	2.6	5.0		5.9
Angelina	*Rz1* + *Rz2* check	9733	60.21	15.2	5.3	39.1	57.5		1.9
Beta G017R	*Rz2* check	9709	65.03	14.7	5.3	34.2	63.4		1.3
$LSD_{0.05}$		2459.0	13.82	1.9	0.7	11.4	15.6		1.6
CV		34.2	29.92	12.6	9.3	73.3	48.6		41.3
Test 408[§§§]									
07-FC1036	RZM-ER-CR-% 05-FC no.		28.64		3.6	74.0	87.2		2.3
Roberta	*rzrz* check		17.66		5.9	34.6	40.1		6.3
Beta 4430R	*Rz1* check		32.55		3.4	79.6	90.0		2.7
Beta G017R	*Rz2* check		30.05		3.5	80.5	97.3		2.7
Angelina	*Rz1* + *Rz2* check		34.58		4.1	70.4	81.7		1.0
$LSD_{0.05}$			3.27		0.54	13.97	10.56		1.0
CV			11.0		11.43	19.85	11.07		29.9

[†]Root yield × % sugar.

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

[§]*%R*, % resistant roots. With severe rhizomania, the reaction of the *Rz1* gene can often be divided into roots from 0 to 4 or 0 to 5 for resistance and 5- or 6 to 9 for susceptibility. This judgment is often made at harvest based on reaction of differential checks. Then % resistant (0–4) = (total number roots in disease-index classes 0–4/total roots harvested) × 100; % R (0–5) = (total number roots in disease-index classes 0–5/total roots harvested) 100; and %R (0–5) = (total number roots in disease-index classes 0–5/total harvested) × 100.

[¶]1 = dark green, 2 = green, 3 = light green, 4 = mostly yellow, 5 = 100% uniformly yellow.

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

[‡‡]1-row plots, 6.7 m, randomized complete block (RCB) experimental design, 8 replications, planted 4 May 2005, harvested 17 Oct. 2005 in plots with only normal strain of BNYVV, the cause of rhizomania present.

[§§]*Rz1* and *Rz2* are the two most commonly deployed dominant resistance genes to protect against rhizomania. RB-BNYVV has defeated *Rz1* but not *Rz2*.

[¶¶]1-row plots, 6.7 m, RCB, 8 replications planted 20 Apr. 2005, harvested 26 Sept. 2005 without evidence of BNYVV in soil.

[##]Experimental hybrids of FC1028 (04-FC1028), FC1037 (04-FC1037), and FC1038 (04-FC1038) test crossed to monogerm tester C833–5CMS. Based on field reaction and pedigree, C833–5CMS is likely *Rz1Rz1*.

[†††]1-row plots, 6.7 m, RCB experimental design, 8 replications, planted 4 May 2005, harvested 13 Oct. 2005 in plots with rhizomania (normal BNYVV) present.

[‡‡‡]1-row plots, 2.7 m, RCB experimental design, 6 replications, planted 12 May 2008 in Hartnell field, harvested 6 Nov. 2008. Hartnell field was heavily infested with both BNYVV and RB-BNYVV.

[§§§]1-row plots, 2.7 m, RCB experimental design, 6 replications, planted 2 May 2008, harvested 22 Oct. 2008 in plots with rhizomania (BNYVV) present.

Table 2. USDA entries 04-FC1028, 05-, 06-, 07-FC1036, 04-FC1037, and 04-FC1038 in the Betaseed, Inc., Cercospora leaf spot nursery at Rosemount, MN.

Variety	Description	2006		2007		2008
		Final rating†	Mean	Final rating	Mean	Final rating
		0–9‡				
04-FC1028	RZM-% FC20021028	7.0	4.7	—	—	3.7
05-FC1036	RZM(04-1028, -1037,-1038)	7.0	4.5	4.8	2.5	—
06-FC1036	RZM(04-1028, -1037,-1038)	—	—	4.3	2.5	—
07-FC1036	RZM(04-1028, -1037,-1038)	—	—	—	—	4.7
04-FC1037	RZM-% FC20021037	6.6	4.2	4.8	2.9	4.0
04-FC1038	RZM-% FC20021038	6.8	4.4	4.2	2.5	5.7
Betaseed, Inc.	Tolerant check	4.5	3.0	3.4	1.9	—
Betaseed, Inc.	Susceptible check	9.0	6.6	7.8	5.7	—
((FC504CMSXFC502/2)XSP6322-0)	USDA-ARS tolerant check	—	—	—	—	2.3
SP351069-0	USDA-ARS susceptible check	—	—	—	—	6.7
$LSD_{0.05}$		0.79	0.49	0.79	0.55	0.97
CV (%)		7.97	7.45	9.59	10.51	14.05

†The final rating is usually the most severe of the epiphytotic.

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

Table 3. FC1028 (04-FC1028), FC1036 (05, 06, 07-FC1036), FC1037 (04-FC1037), and FC1038 (04-FC1038), an experimental hybrid of FC1036, and checks were tested during, and after, development in the USDA-ARS joint Beet Sugar Development Foundation's beet curly top nursery near Kimberly, ID.

Variety	Description	Disease index, final rating		
		13 Sept. 2005	11 Sept. 2006†	23 July 2008†
		0–9‡		
04-FC1028	RZM-% FC20021028	6.3	—	5.8
05-FC1036	RZM(04-1028, -1037, -1038)	—	5.3	6.2
06-FC1036	RZM(04-1028, -1037, -1038)	—	—	5.8
07-FC1036	RZM(04-1028, -1037, -1038)	—	—	6.2
04-FC1037	RZM-% FC20021037	6.0	—	6.0
04-FC1038	RZM-% FC20021038	5.0	—	5.8
05-FC1036H5	C790-15cms × 05-FC1036	4.5	5.3	5.3
05-FC1036H50	C833-5cms × 05-FC1036	5.3	—	5.3
HM-PM21	Resistant check	4.55(4)§	—	—
US H11	Resistant check	4.60(2)	4.3(3)	—
03-, 04-C37	Resistant check	4.52(5)	—	—
Beta G6040	Resistant check	—	—	4.8
HM-E17	Susceptible check	7.0	—	—
Monohikari	Susceptible check	7.45	7.5(5)	—
19941027	Susceptible check	—	—	7.0
$LSD_{0.05}$		¶	0.8	0.93
CV (%)		—	12.4	9.67

†The germplasm and their experimental hybrids were tested in two different experiments in the 2006 and 2008 curly top screening nurseries at Kimberly, ID.

‡1 = no symptoms; 9 = dead.

§The number in parentheses after the rating in a check variety is the number of times that check was in the test as an entry (with 3 replications each time).

¶The design was not randomized and a statistical analysis would not be appropriate.

moderate resistance to BCTV and, based on their pedigree, should have some potential for selection of higher resistance to BCTV.

Aphanomyces Root Rot (Aphanomyces Black Root)

The germplasms were evaluated for resistance to Aphanomyces root rot in a field nursery near Shakopee, MN by Betaseed (Panella et al., 2008). A visual rating scale of 1 to 9 based on stand persistence and plant health was used

Table 4. USDA entries 4-FC1028, 05-, 06-, 07-FC1036, 04-FC1037, and 04-FC1038 in the Betaseed Aphanomyces root rot nurseries at Shakopee, MN in 2006 and 2008.

Variety	Description	2006		2008	
		First rating	Second rating†	First rating	Second rating†
		0–9‡			
04-FC1028	RZM-% FC20021028	4.7	5.0	1.7	2.0
05-FC1036	RZM(04-1028, -037, -1038)	3.7	3.8	—	—
07-FC1036	RZM(04-1028, -1037, -1038)	—	—	1.7	2.7
04-FC1037	RZM-% FC20021037	2.8	3.2	2.1	2.9
04-FC1038	RZM-% FC20021038	3.8	3.8	2.6	3.5
Tolerant check	Betaseed, Inc.	2.3	1.5	1.2	1.9
Susceptible check	Betaseed, Inc.	5.5	6.7	3.3	5.3
$LSD_{0.05}$		1.31	1.47	1.15	0.98
CV (%)		23.41	25.72	31.36	19.96

†Two ratings are made but the second, more severe, rating is the more meaningful.

‡1 = no symptoms; 9 = dead plants.

to evaluate damage from Aphanomyces root rot. A rating of 1 is a complete stand of healthy beets and a rating of 9 has 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 and J. Miller, personal communication, 2008).

In the Aphanomyces evaluation of 2006 at the second reading, all four germplasms—FC1028 (04-FC1028), FC1037 (04-FC1037), FC1038 (04-FC1038), and FC1036 (05-FC1036)—were significantly more tolerant than the susceptible check and significantly less resistant than the resistant check (Table 4). In 2008, at the second reading, all four germplasms—FC1028 (04-FC1028), FC1037 (04-FC1037), FC1038 (04-FC1038), and FC1036 (07-FC1036)—were significantly more tolerant than the susceptible check. FC1028 and FC1036 were not significantly different from the resistant control. FC1037 and FC1038 were significantly less tolerant than the resistant check. FC1036 and FC1028 had resistance to Aphanomyces root rot, and FC1037 and FC1038 showed only a 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, CA (Table 5) as previously described (Panella et al., 2008). The disease index was determined by visually rating each root in a single row plot on a scale of 0 (disease free) to 7 (dead and rotted). Experiments were planted in a completely randomized blocked design with 5 replications in 4-m single-row plots. 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 used.

Looking at the disease index over 3 yr of testing, FC1028 was not significantly different from the susceptible check and was significantly less resistant than the resistant control (Table 5). Although an early selection from FC1036 (04-FC1036) showed a little resistance to Rhizoctonia root and crown rot (Table 5, 2006); in 2009, the finished FC1036 (07-FC1036, 08-FC1036) germplasms were not significantly different from the susceptible control and were significantly less resistant than the resistant control (Table 5, 2009). FC1038 was significantly more tolerant than the susceptible check in 2006 and 2008 but performed poorly in 2009. FC1037 performed best overall: it was significantly more tolerant than the susceptible check and not significantly different from the resistant check in 2006 and 2008, although it was not significantly different from the susceptible check in 2009 (Table 5).

Availability

Breeder seed of FC1028, FC1037, FC1038, and FC1036 is maintained by 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 have been deposited in the National Plant Germplasm System, where it will be available for research purposes, including development and commercialization of new cultivars, immediately. 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 FC1028, FC1037, FC1038, and FC1036.

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Table 5. Rhizoctonia root and crown rot resistance evaluations in Fort Collins, CO for 04-FC1028, 08-FC1036/07-FC1036 in 2009 6R, 04-FC1037, and 04-FC1038.

	2006 (5R)			2008 (7R)		
Description	Disease index	Healthy†	Harvestable‡	Disease index	Healthy†	Harvestable‡
	0–7§	%		0–7§	%	
04-FC1028	3.9	18.4	40.4	4.6	5.0	22.4
05-FC1036	3.2	19.2	48.1	—	—	—
04-FC1037	3.0	27.3	57.7	2.7	3.3	48.3
04-FC1038	3.3	20.5	50.2	2.9	3.1	42.0
FC901/C817 (susceptible check)	4.2	11.7	31.9	4.3	0.0	24.5
FC703 (resistant check)	2.2	32.8	72.4	2.3	0.0	58.7
FC705/1 (highly resistant check)	1.8	30.8	85.9	2.2	0.0	79.8
Experiment mean	3.5	19.5	48.3	3.4	0.9	36.8
$LSD_{0.05}$	1.18	19.5	20.1	0.95	NS	19.21
CV (%)	—	—	—	22.65	—	41.73

	2009 (6R)¶			2009 (8R)¶		
Description	Disease index	Healthy†	Harvestable‡	Disease index	Healthy†	Harvestable‡
	0–7§	%		0–7§	%	
04-FC1028	5.5	0.0	10.3	—	—	—
04-FC1037	—	—	—	4.2	0.0	33.5
04-FC1038	—	—	—	5.4	6.6	13.4
07-FC1036	4.7	5.3	22.1	—	—	—
08-FC1036	4.6	0.0	20.2	—	—	—
FC901/C817 (susceptible check)	5.0	3.9	8.3	4.9	8.6	21.3
FC703 (resistant check)	3.0	17.5	51.7	2.9	21.4	62.6
FC705/1 (highly resistant check)	2.1	37.1	75.7	2.2	42.5	71.2
Experiment mean	5.4	3.8	14.0	4.3	10.7	35.6
$LSD_{0.05}$	0.89	9.41	16.7	1.04	15.4	21.5
CV (%)	13.3	198	96	19.4	115	48

†0 = healthy; 7 = dead.

‡Percentage of healthy roots (disease index classes 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 classes 0 through 3 combined). Percentages were transformed using arcsin-square root to normalize the data for analyzes.

¶Data summary is from two experiments at the same location treated as totally separate experiments with different randomization, another set of checks, etc. Two different seed productions of FC1036 were tested in 6R.

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