Registration of F1024 Sugarbeet Germplasm with Resistance to Sugarbeet Root Maggot

L. G. Campbell,* L. Panella, and A. C. Smigocki

ABSTRACT

F1024 (Reg. No. GP-272, PI 658654) sugarbeet (*Beta vulgaris* L.) germplasm with resistance to sugarbeet root maggot (*Tetanops myopaeformis* von Röder) was released by the USDA-ARS and the North Dakota Agricultural Experiment Station, North Dakota State University, Fargo, ND on 15 Dec. 2009. F1024 was selected from a population formed by crossing F1016, a germplasm line resistant to root maggot, with a breeding line resistant to Cercospora leaf spot (CLS; caused by *Cercospora beticola* Sacc.). The population was subjected to three cycles of mass selection for resistance to root maggot followed by three cycles of selection among half-sib families. Under natural root maggot infestations, F1024 had a damage rating of 2.1 (on a scale of 1 to 9, where 0 = no maggot feeding, and 9 = >75% of root surface with feeding scars), compared with an average of 6.1 for two susceptible commercial hybrids. In a 2009 CLS evaluation, F1024 had a significantly lower disease rating than the susceptible check, and the difference between F1024 and the resistant checks was not significant. The performance of testcross hybrids between the component half-sib families of F1024 and a susceptible cytoplasmic-male-sterile line provided additional validation of the potential of root maggot–resistant hybrids in areas where root maggot is a perpetual threat.

F1024 (Reg. No. GP-272, PI 658654), a sugarbeet (*Beta vulgaris* L.) germplasm with resistance to sugarbeet root maggot (*Tetanops myopaeformis* von Röder), was released by the USDA-ARS and the North Dakota Agricultural Experiment Station, North Dakota State University, Fargo, ND on 15 Dec. 2009. F1024 will expedite the incorporation of resistance to sugarbeet root maggot into elite populations and the subsequent production of resistant hybrids that are adapted to areas where the root maggot is a relentless pest. One advantage of F1024 over previously released root maggot–resistant germplasm is its improved resistance to Cercospora leaf spot (CLS; caused by *Cercospora beticola* Sacc.), a destructive foliar disease of sugarbeet that occurs in many production areas (Jacobsen and Franc, 2009).

Sugarbeet root maggot is a major insect pest of sugarbeet in the central and intermountain regions of the USA and in Alberta, Canada. Adult flies emerge from previous year's sugarbeet fields in the late spring or early summer and deposit eggs at the base of sugarbeet seedlings. The resulting larvae feed on the root surface until late July or early August. Reductions in yield (Campbell et al., 1998) may be the result of stand loss early in the season, but damage occurs primarily from larvae feeding throughout the growing season. The larvae overwinter in the soil, migrate to near the surface in late spring, and form pupae just below the surface for a short time before the adults emerge (Hein et al., 2009).

Genetic variability for resistance to the root maggot has been recognized since the early 1980s (Theurer et al., 1982; Campbell, 2005), but only two root maggot–resistant germplasm lines, F1015 (PI 605413) and F1016 (PI 608437), have been available to the public (Campbell et al., 2000). In a seedling bioassay (Smigocki et al., 2006), second-instar root maggot larvae feeding on the roots of susceptible 3-wk-old seedlings were more prominent than on resistant seedlings. Analysis of root maggot–responsive genes in F1016 yielded more than 150 genes, among them a serine protease inhibitor with a potential function in the mechanism of resistance (Puthoff and Smigocki, 2006). Serine proteases have a functional role in the gut of root maggot larvae (Wilhite et al., 2000).

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Abbreviations: CLS, Cercospora leaf spot; CMS, cytoplasmic male sterile.

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In a trial comparing four experimental hybrids with root maggot–resistant pollinators and two susceptible hybrids with and without applied insecticide at sites with substantial root maggot populations, hybrids with the maggot-resistant pollinators and no insecticides applied had root yields equal to those of the root maggot–susceptible hybrids with insecticide applied (Campbell et al., 2008). Another trial comparing four hybrids with F1015, a root maggot–resistant germplasm, as the pollinator and susceptible cytoplasmic-male-sterile (CMS) females also indicated that hybrids with a resistant pollinator would have substantial resistance to the root maggot (Campbell and Niehaus, 2008). These two studies encompassed six environments, four maggot-resistant pollinators, and five elite female (CMS) parental lines.

Methods

F1024 was selected from a population formed by crossing F1016, a line with green hypocotyls, and 19961009H2, a breeding line developed by the USDA-ARS, Fort Collins, CO. The population was formed by allowing plants of F1016 and 19961009H2 plants with red hypocotyls to randomly interpollinate. Seed was harvested from only the F1016 plants. Forty-nine F_1 progeny with red hypocotyls were harvested to provide seed for the F_2 generation; plants with green hypocotyls were rogued as seedlings.

F1016 is a multigerm, diploid line selected almost exclusively for resistance to sugarbeet root maggot (Campbell et al., 2000). 19961009H2 is the F_1 hybrid of FC709–2 × FC907 (Panella et al., 2008). FC709–2 (PI 599668) is a multigerm germplasm with excellent resistance to Rhizoctonia root rot (caused by *Rhizoctonia solani* J.G. Kühn) and moderate resistance to CLS (Panella, 1999). FC907 is a (FC701 [PI 590661] × FC607 [PI 590837]) BC_4 backcrossed to FC607 to enhance the resistance to CLS (Hecker and Gaskill, 1972; Smith and Ruppel, 1980). FC907 was an attempt to create a multigerm pollinator with resistance to CLS but was never released. It had substantial resistance to CLS but little resistance to Rhizoctonia root rot; moreover, it was more than 90% monogerm.

Between 2000 and 2003, the population from which F1024 was selected was subjected to three cycles of mass selection. All evaluations were based on natural infestations of sugarbeet root maggot. For each cycle, approximately 1000 plants were dug by hand and washed. Between 50 and 68 plants with the least amount of visible sugarbeet root maggot damage were selected and allowed to interpollinate to produce seed for the next selection cycle. Fanged roots or roots with severed taproots were discarded; all selected roots had well-developed taproots with a minimal amount of maggot scaring at all depths.

Plants from the third selection cycle were compared with the susceptible parent (19961009H2) via an in vitro seedling bioassay (Smigocki et al., 2006). Three-week-old seedlings were washed to remove residual soil and gently blotted to remove excess water. Five to 10 seedlings were placed in a 150- × 15-mm Petri plate and kept moist by adding water directly to the plates, or alternatively, seedlings were placed on wet nylon membranes. Twenty second-instar larvae were placed in a clump on the roots, and the plates were sealed with paraffin and incubated at 25°C in the dark. Dispersion of the larvae was observed 4 h later.

Selected plants from the third cycle were harvested individually, and seed from each plant was increased as a half-sib family. Forty-eight half-sib families were evaluated in 2005 and 14 were selected for a second cycle of selection in 2007. Ten of the 14 families were evaluated again in 2008 and eight of the ten were selected. Selected plants from these eight families were allowed to interpollinate, and an equal amount of seed from each of the eight lines was combined to form the original seed of F1024.

Half-sib families were evaluated for root maggot resistance in replicated field trials near St. Thomas, ND. Plots were two rows wide and 9 m long. In each of two replicates, five consecutive roots from the center of each row were hand dug, washed, and rated on a scale of 0 (no damage) to 9 (more than 0.75% of the root surface blackened by scars) for root maggot damage (Campbell, 2005), and families with relatively low damage ratings were identified. Twelve to 27 plants from families with relatively low damage ratings were selected from a third replicate to produce seed for the next cycle. All of the plants from the selected families, except those on the ends of the rows, were hand dug and washed. Roots with well-developed single taproots and the least amount of root maggot damage were selected for advancement. The 2007 evaluations were confounded by moderate wireworm (*Hemicrepidius memnonius* and *Limonius* spp.) feeding, making root maggot damage assessment more subjective than in 2005 and 2008.

Root yield and sucrose concentration of the half-sib families in the absence of root maggot were evaluated in replicated yield trials at Fargo, ND in 2007 and 2008. Two adapted hybrids, ACH-817 (Crystal Beet Seed, Moorhead, MN) and Beta-6600 (Betaseed, Shakopee, MN) and two root maggot–resistant germplasms, F1015 and F1016, were included for comparisons. The experimental design was an RCB with four replicates in 2006; because of excessive moisture, only two replicates were harvested in 2008. Experimental units were two rows wide and 10 m long with 56 cm between rows. Weeds were controlled with registered sugarbeet herbicides, cultivation, and hand weeding when needed. The root yield was measured as the weight of all roots from a single plot at the time of harvest. The sucrose concentration was determined by polarimetry and based on a random sample of 10–12 roots from each plot.

The half-sib families also were included in specialized nurseries to obtain an initial assessment of disease development when exposed to *C. beticola* and *Aphanomyces cochlioides* Drechs. (the causal organism of Aphanomyces root rot). The CLS nursery was located near East Lansing, MI (USDA-ARS) in 2006 and near Rosemount, MN (Betaseed, Shakopee, MN) in 2007. The nursery for Aphanomyces root rot was near Shakopee, MN (Betaseed). F1024 also was evaluated for Rhizoctonia root rot in a nursery at Fort Collins, CO in 2009. These nurseries were located and managed with the objective of providing a reliable indication of the response to a single disease organism with minimal complications due to other diseases (Panella et al., 2008).

Each nursery included entries from other breeding programs and representative resistant and susceptible cultivars selected by nursery managers.

Testcross hybrids were formed by crossing the eight component lines of F1024 with a common root maggot–susceptible proprietary CMS line (Betaseed) and were evaluated at sites with root maggot near St. Thomas, ND and at sites without root maggot at Fargo, ND. Root yield, sucrose concentration, and sugar yield were measured at St. Thomas in 2007 and 2008 and at Fargo in 2007–2009. The experimental design was an RCB with four replicates. Individual experimental units at St. Thomas were four-row, 10-m-long plots with rows spaced 56 cm apart. The center two rows were harvested for yield and quality determinations, and five roots from the center of each of the two outside rows were hand dug, washed, and rated for root maggot damage (Campbell, 2005). The experimental units at Fargo were two rows wide. Because of adverse conditions at harvest, only two replicates were harvested at Fargo in 2008. Two adapted, root maggot–susceptible hybrids—ACH-817 and Beta-6600—were included in the trials. The root yield was measured as the weight of all roots from a single plot at harvest. The measurements of sucrose concentration and sucrose loss to molasses were based on a random sample of 10–12 roots from each plot. Sodium, potassium, and amino-nitrogen concentration were used to calculate loss to molasses using the formula that American Crystal Sugar Co. (Moorhead, MN) uses to determine payments to growers. Sugar yield was defined as (sucrose concentration – sucrose loss to molasses) × root yield.

Data from each environment were analyzed using general linear models calculated with SAS statistical software (SAS 9.1. SAS Institute, Inc., Cary, NC) with all factors considered fixed (Littell et al., 2002). The ESTIMATE function of the SAS GLM procedure was used to calculate the magnitude of the difference between the average of the testcross hybrids and the otherwise adapted susceptible hybrid.

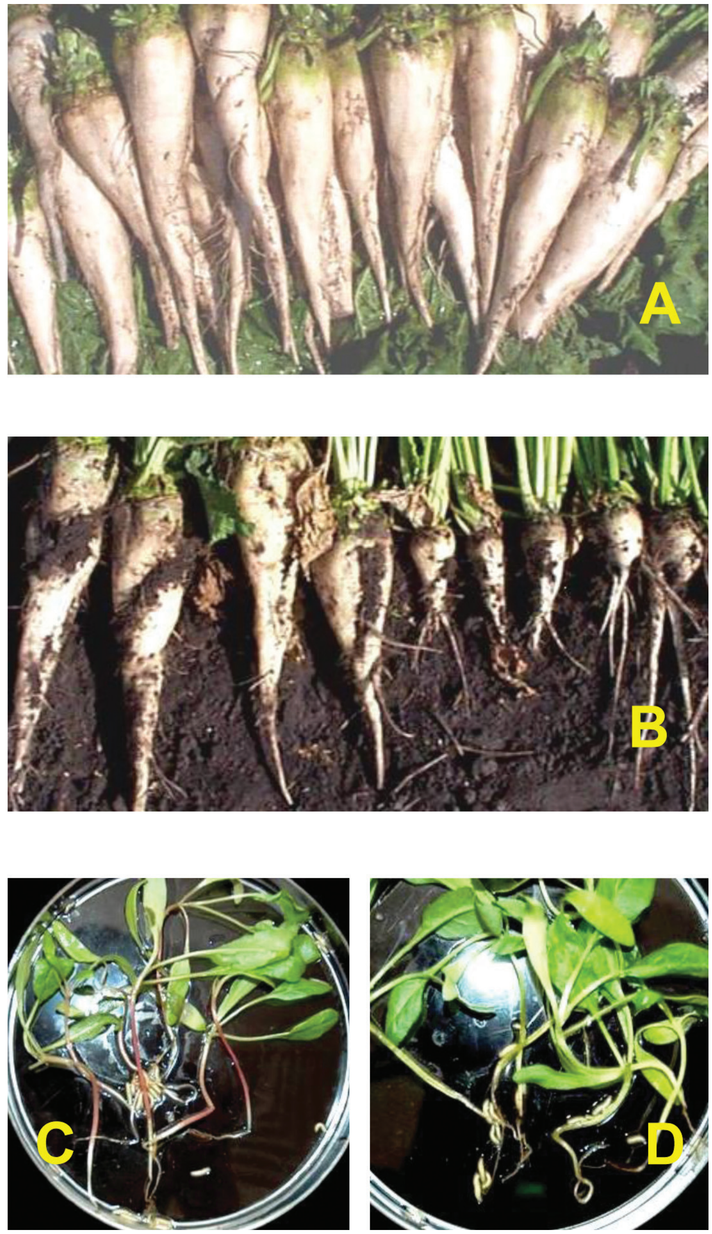

Figure 1. Comparison of sugarbeet root maggot damage (A) on roots of the population from which F1024 was selected, after three cycles of mass selection and (B) on a susceptible adapted hybrid, St. Thomas, ND 2005; (C) root maggot larvae on seedlings from the population that gave rise to F1024 after three cycles of mass selection for maggot resistance and (D) on seedlings of 19961009H2, the root maggot-susceptible parent in the cross from which F1024 was selected.

Characteristics

F1024 is a multigerm diploid sugarbeet germplasm that segregates for hypocotyl color in an approximate ratio of one green to three red. The roots of F1024 are white, tapered (narrow triangular), and unbranched with a relative shallow groove (Fig. 1A). The roots are larger and longer than those of F1016, its root maggot–resistant parent, and F1024 plants are generally larger and more vigorous than those of F1016.

Three cycles of mass selection decreased the rating for sugarbeet root maggot damage of the population under selection (Fig. 1A) from 5.3 to 2.9 (Fig. 2). During those 4 yr, susceptible adapted hybrids (Fig. 1B) had ratings ranging from 5.9 to 6.5, for an average of 6.2 (Fig. 2). The response of root maggot larvae in the in vitro seedling bioassay provided further evidence of the resistance of the selected population (Smigocki et al., 2006). Most larvae on plants from the third selection cycle were clustered and not actively feeding; a few had moved away from the other larvae and any sugarbeet roots (Fig. 1C). In comparison, larvae were aligned along the roots of the susceptible parent (19961009H2) and appeared to be actively feeding 4 h after being placed in the Petri dishes (Fig. 1D). A similar differential response was observed in an earlier comparison of F1010 (PI 535818), a root maggot–susceptible germplasm in the parentage of F1016, with F1016, the resistant parent in the cross from which F1024 was selected (Smigocki et al., 2006).

The average rating for root maggot damage for all half-sib families evaluated in 2005 and 2008 was 2.9 and 2.8, respectively. The families selected for advancement in 2005 had an average damage rating of 2.2. In 2008 the average

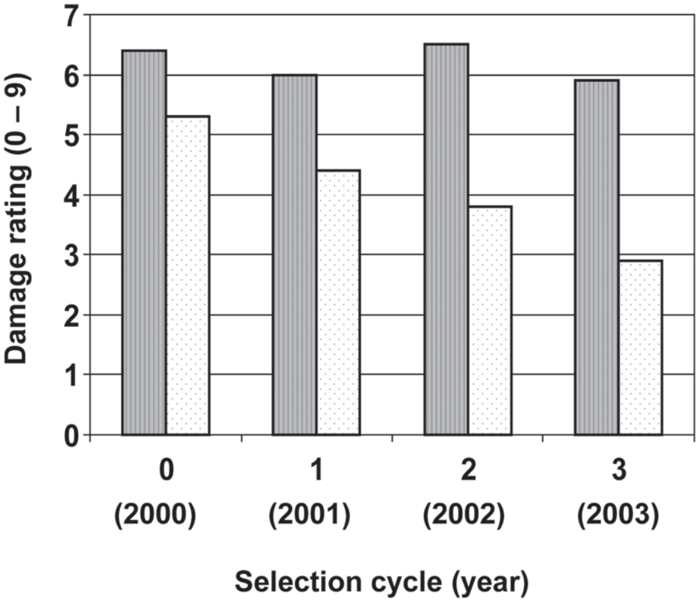

Figure 2. Damage ratings of an adapted susceptible hybrid for sugarbeet root maggot (shaded bars) and the response to three cycles of mass selection for sugarbeet root maggot–resistance in the population that produced F1024 (light-colored bars), St. Thomas, ND, 2000–2003. The difference between the susceptible hybrid and the population was significant (P = 0.05) in all years. Root maggot damage was rated on a scale of 0 (no damage) to 9 (more that 0.75% of the root surface blackened by scars).

damage rating of the eight selected families was 1.1 (Table 1). The adapted hybrids had damage ratings of 6.2 in 2005 and 4.2 in 2008. The average root yield of the eight selected families (Table 1) was approximately half the root yield of the adapted hybrids in the absence of root maggot. The average sucrose concentration of the selected families was about 20 g kg^{-1} lower than the average of the two adapted hybrids at Fargo.

In the 2006 CLS evaluations (Table 2), the difference between the average disease rating of the tolerant checks and 13 of the 25 disease ratings (half-sib family by date combinations) of the half-sib families recorded between 9 August and 5 September was not significant. The differences between 7 disease ratings of the half-sib families and the susceptible checks were not significant, and 3 of the disease ratings of the half-sib families were between the tolerant checks and the susceptible checks. Two half-sib families had disease ratings on 5 September that were not different (P = 0.05) from either the tolerant or the susceptible check. The average CLS disease rating for all of the half-sib families across the four observation dates in 2006 was 5.4, compared with 8.4 for the susceptible checks and 3.8 for the tolerant checks. The difference between the disease ratings of the tolerant checks and 12 of the 32 diseases ratings of the half-sib families recorded between 26 July and 15 Aug. 2007 was not significant (Table 2). Nineteen of the 2007 CLS disease ratings for the half-sib families were between those of the tolerant and susceptible checks, and one observation on 26 July did not differ from the susceptible check. The average CLS disease rating of the half-sib families across the four observation dates in 2007 was 3.1, compared with 5.7 for the susceptible checks and 2.0 for the tolerant checks. All of the half-sib families had relatively high Aphanomyces root rot ratings at Shakopee in 2007 (Table 2).

Table 1. Root yield, sucrose concentration, and damage ratings for sugarbeet root maggot of the eight component lines of F1024, Fargo, ND and St. Thomas, ND, 2005–2008.

	Fargo, ND				St. Thomas, ND	
	Root yield		Sucrose		Root maggot damage	
Half-sib family	2007	2008	2007	2008	2005	2008
	Mg ha^{-1}		g kg^{-1}		0–9†	
HS1024–1	38.5 bc‡	43.3 cd	121 bc	127 c	2.3 b	1.1 bc
HS1024–2	30.7 cd	25.2 ef	124 b	135 c	2.0 b	1.0 bc
HS1024–3	31.4 c	32.1 e	119 bc	134 c	2.2 b	1.0 bc
HS1024–4	40.1 b	28.8 ef	126 b	139 bc	2.3 b	0.9 c
HS1024–5	33.3 bc	33.9 de	123 bc	131 c	1.9 b	1.2 bc
HS1024–6	33.1 bc	18.8 f	121 bc	129 c	2.2 b	1.3 bc
HS1024–7	33.6 bc	23.4 ef	124 bc	137 bc	2.3 b	1.2 bc
HS1024–8	22.5 d	19.2 f	122 bc	125 c	2.4 b	0.9 c
Mean	32.9	28.1	123	132	2.2	1.1
ACH-817	60.2 a	52.4 bc	144 a	157 a	—	4.2 a
Beta-6600	60.5 a	63.7 a	147 a	153 ab	6.2 a	—
F1015	61.3 a	55.6 ab	127 b	126 c	—	—
F1016	34.6 bc	27.6 ef	114 c	133 c	—	1.6 b
$LSD_{0.05}$	8.4	11.1	10	17	1.2	0.7

†Damage rating: 0, no feeding scars; 1, one to four small scars; 2, five to ten small scars; 3, up to three large scars or numerous small scars; 4, a few large scars or considerable feeding on lateral roots; 5 several large scars and/or extensive feeding on lateral roots; 6, numerous scars, up to 25% of root surface blackened; 7, 25–50% of root blackened with scars; 8, 50–75% of root surface blackened; 9, >75% of root blackened.

‡Differences among means within a column followed by the same letter are not significant according to Fisher's protected LSD (P = 0.05).

Table 2. Disease indices of the eight component lines of F1024 in nurseries to evaluate response to Cercospora leaf spot and Aphanomyces root rot.

Half-sib family	Disease index								
	Cercospora leaf spot								Aphanomyces
	2006				2007				2007
	9 Aug.	15 Aug.	22 Aug.	5 Sept.	26 July	2 Aug.	8 Aug.	15 Aug.	
	1–10†		1–9		1–10				1–9
HS1024–1	5.3+‡	6.7–	6.3–	5.5±	1.4+	2.0+	3.7	4.4	5.6–
HS1024–2	7.3–	7.0–	7.0–	5.7±	2.0–	3.0	4.8	5.7	4.6
HS1024–3	3.0+	5.0+	4.5+	—	1.0+	2.6	3.0+	4.1+	5.1
HS1024–4	6.0+	7.0–	6.3–	4.0+	1.7+	2.6	3.7	4.7	5.7–
HS1024–5	5.5+	—	5.5	—	1.7+	3.0	4.4	5.9	4.5
HS1024–6	4.0+	5.5+	5.5	5.0+	1.7+	2.7	3.7	5.1	5.2
HS1024–7	4.0+	4.7+	5.3	4.5+	1.0+	2.4	3.1+	3.7+	6.3–
HS1024–8	—	—	—	—	1.4+	2.4	3.4	4.4	6.2–
Mean	5.0	6.0	5.8	4.9	1.5	2.6	3.7	4.8	5.4
Susceptible checks	9.7	8.7	8.0	7.0	2.7	5.0	7.1	7.8	6.4
Tolerant checks	3.7	3.3	3.3	4.7	1.0	1.0	2.4	3.4	2.3
$LSD_{0.05}$	3.1	2.2	1.9	1.5	0.7	1.0	0.8	0.8	0.9

† Higher disease indices are indicative of increased severity in all cases (1 = no visible symptoms).

‡ Disease indices within a column followed by a plus sign (+) do not differ from the tolerant checks, according to Fisher's protected LSD (*P* = 0.05); disease indices followed by a negative sign (–) are not different from the susceptible checks.

F1024 had a root maggot damage rating of 2.1 at St. Thomas in 2009, compared with ratings of 2.5 for F1016, 3.4 for F1015, 6.0 for Beta-2084, and 6.1 for ACH-820 ($LSD_{0.05}$ = 1.0). The sucrose concentration of F1024 at Fargo in 2009 was 137 g kg^{-1}, compared with three adapted hybrids that ranged from 147 to 152 g kg^{-1} ($LSD_{0.05}$ = 14). The root yield of F1024 (26.5 Mg ha^{-1}) was less than half of the average of the three adapted hybrids (60.8 Mg ha^{-1}). In the 2009 CLS evaluations at East Lansing, F1024 had a disease rating of 2.2, the tolerant checks had disease ratings of 1.5 and 1.9, the susceptible check a rating of 5.5, and F1016 a rating of 3.6 ($LSD_{0.05}$ = 0.8). The difference between the Rhizoctonia root rot disease rating for F1024 (6.3) and FC-709, the resistant check, (3.0) in the 2009 evaluation nursery at Ft. Collins was significant ($LSD_{0.05}$ = 0.9); the susceptible check, FC901/C817, had a disease rating of 5.0.

Testcross Hybrids

All differences between the root maggot damage ratings of the testcross hybrids and the susceptible commercial hybrids (ACH-817 and Beta-6600) were significant in 2007 and 2008 (Table 3). In 2007, the average damage rating of the eight testcross hybrids was 3.4, compared with a damage rating of 6.0 for Beta-6600. The average damage rating of the testcross hybrids in 2008 was 2.7; the two commercial hybrids had an average damage rating of 4.6. Differences in stand reduction between the time the larvae began feeding and harvest may have increased the root-yield differences between the susceptible hybrid and the testcross hybrids at St. Thomas in 2007 (Table 4). Stand losses for the testcross hybrids ranged from 7 to 15%, compared with a stand loss of 27% for Beta-6600 ($LSD_{0.05}$ = 9%). Stand reductions were lower at St. Thomas in 2008 than in 2007, and in some cases, differences between the commercial hybrids and the testcross hybrids were not significant.

The relative root yields at St. Thomas followed a pattern similar to that observed for root maggot damage ratings. In both 2007 and 2008, the root yields of the susceptible adapted hybrids were lower than those of all of the testcross hybrids (Table 3). In 2007, the average root yield of the testcross hybrids was 10.7 Mg ha^{-1} (SE = 1.7) greater than the root yield of Beta-6600 (Table 4). The difference between the average yield of the testcross hybrids and the average yield of the two commercial hybrids in 2008 was 12.3 Mg ha^{-1} (SE = 1.5). At Fargo, in the absence of root maggot, there were no significant differences in root yield among the hybrids in 2007 or 2008 (Tables 3 and 4); in 2009, the differences between six of the eight testcross hybrids and the commercial hybrids were not significant (Table 3). In all environments except St. Thomas in 2007, the sucrose concentration of the adapted hybrid or hybrids was greater than the sucrose concentration of all the testcross hybrids; however, significant differences were observed only at St. Thomas in 2008 and Fargo in 2007 (Table 3).

Availability

F1024 will be maintained by the USDA-ARS, Fargo, ND and freely distributed in quantities sufficient for reproduction. Requests for seed should be directed to the Sugarbeet and Potato Research Unit, USDA-AS, Fargo, ND. A seed sample also has been deposited with the USDA National Plant Germplasm Center, where it will be available for research purposes, including the development of commercial lines and cultivars. U.S. Plant Variety Protection will not be pursued for F1024. It is requested that appropriate recognition be made when this germplasm contributes to the development of an improved breeding line, cultivar, or hybrid.

Table 3. Root yield, sucrose concentration, sugar yield, and damage ratings for sugarbeet root maggot of testcross hybrids formed by pollinating a root maggot–susceptible, cytoplasmic-male-sterile line with the eight component lines of F1024 and two susceptible adapted hybrids, St. Thomas and Fargo, ND, 2007–2009.

Pollinator or adapted hybrid	St. Thomas, ND 2007	St. Thomas, ND 2008	Fargo, ND 2007	Fargo, ND 2008	Fargo, ND 2009
			Root yield (Mg ha^{-1})		
HS1024–1	44.3 bc†	54.6 ab	71.5 a	64.4 a	49.2 b-e
HS1024–2	45.0 a-c	50.1 b	58.0 a	64.5 a	59.2 a
HS1024–3	48.7 a	57.1 a	66.7 a	67.0 a	53.0 b
HS1024–4	41.6 c	52.4 b	65.9 a	66.0 a	44.4 de
HS1024–5	44.4 bc	52.4 b	62.2 a	63.5 a	45.0 de
HS1024–6	45.9 ab	57.3 a	64.5 a	64.4 a	43.2 e
HS1024–7	42.3 bc	54.4 ab	59.1 a	63.0 a	51.7 bc
HS1024–8	41.7 c	51.4 b	59.3 a	61.7 a	49.9 b-d
ACH-817	—	39.9 c	60.2 a	52.4 a	45.7 c-e
Beta-6600	33.5 d	42.9 c	60.5 a	63.7 a	45.8 c-e
			Sucrose (g kg^{-1})		
HS1024–1	130 a	144 de	125 e	140 a	139 a
HS1024–2	131 a	145 d	136 b-d	142 a	138 a
HS1024–3	137 a	147 cd	136 b-d	144 a	144 a
HS1024–4	134 a	138 e	134 c-e	142 a	140 a
HS1024–5	132 a	147 cd	127 de	137 a	140 a
HS1024–6	136 a	145 d	135 b-d	145 a	140 a
HS1024–7	134 a	151 bc	141 a-c	149 a	141 a
HS1024–8	134 a	142 de	133 c-e	143 a	140 a
ACH-817	—	153 ab	144 ab	157 a	147 a
Beta-6600	131 a	158 a	147 a	153 a	147 a
			Sugar yield (kg ha^{-1})		
HS1024–1	4881 c	6824 ab	6412 a	7876 a	6023 b-d
HS1024–2	5050 bc	6303 bc	6329 a	8171 a	7297 a
HS1024–3	5743 a	7363 a	7264 a	8735 a	6916 ab
HS1024–4	4809 c	6185 bc	6903 a	8231 a	5516 d
HS1024–5	5064 bc	6760 a-c	6232 a	7678 a	5430 d
HS1024–6	5431 ab	7207 a	6617 a	8128 a	5276 d
HS1024–7	4888 c	7305 a	6564 a	8411 a	6505 a-c
HS1024–8	4803 c	6303 bc	5696 a	8020 a	6055 b-d
ACH-817	—	5478 d	6763 a	7408 a	5890 cd
Beta-6600	3772 d	6172 c	6584 a	8738 a	5841 cd
			Sugarbeet root maggot damage (0–9)‡		
HS1024–1	3.6 b	3.2 b	—	—	—
HS1024–2	3.2 b	2.5 bc	—	—	—
HS1024–3	3.1 b	2.7 bc	—	—	—
HS1024–4	3.5 b	2.8 bc	—	—	—
HS1024–5	3.5 b	3.0 bc	—	—	—
HS1024–6	3.6 b	2.4 bc	—	—	—
HS1024–7	3.4 b	2.2 c	—	—	—
HS1024–8	3.4 b	2.8 bc	—	—	—
ACH-817	—	4.7 a	—	—	—
Beta-6600	6.0 a	4.6 a	—	—	—

†Differences among means within a column followed by the same letter are not significant, according to Fisher's protected LSD ($P = 0.05$).

‡Damage rating: 0, no feeding scars; 1, one to four small scars; 2, five to ten small scars; 3, up to three large scars or numerous small scars; 4, a few large scars or considerable feeding on lateral roots; 5 several large scars and/or extensive feed on lateral roots; 6, numerous scars, up to 25% of root surface blackened; 7, 25–50% of root blackened with scars; 8, 50–75%of root surface blackened; 9, >75% of root blackened.

Table 4. Differences in root yield, sucrose concentration, sugar yield, damage ratings for sugarbeet root maggot, and stand loss between the average of eight testcross hybrids with root maggot resistant pollinators and susceptible adapted hybrids, St. Thomas and Fargo, ND, 2007–2009.

Characteristic	St. Thomas, ND 2007	St. Thomas, ND 2008	Fargo, ND 2007	Fargo, ND 2008	Fargo, ND 2009
Root yield (Mg ha^{-1})	10.7† (1.7)	12.3 (1.5)	3.1 (ns)	6.2 (ns)	3.7 (ns)
Sucrose (g kg^{-1})	3 (ns)	−10 (2)	−12 (2)	−12 (4)	−6 (3)
Sugar yield (kg ha^{-1})	1311 (191)	956 (210)	170 (ns)	83 (ns)	261 (ns)
Root maggot damage (0–9)‡	−2.6 (0.2)	−1.9 (0.3)	—	—	—
Stand loss (%)§	−16 (3)	−8 (2)	—	—	—

†The difference is equal to the average of the eight testcross hybrids minus the average of the root maggot–susceptible hybrids. Values in parenthesis are standard errors; "ns" indicates that the difference was not significant; all others were significant ($P = 0.05$).

‡Damage rating: 0, no feeding scars; 1, one to four small scars; 2, five to ten small scars; 3, up to three large scars or numerous small scars; 4, a few large scars or extensive feeding on lateral roots; 5 several large scars or extensive feed on lateral roots; 6, numerous scars, up to 25% of root surface blackened; 7, 25–50% of root blackened with scars; 8, 50–75%of root surface blackened; 9, >75% of root blackened.

§Stand loss is one minus the number of plants at harvest divided by the number of plants before arrival of the root maggots (i.e., depositing of eggs by females; late May or early June).

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