Breeding for Combined Resistance to Leaf Spot and Curly Top in Sugar Beet[1]

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Introduction

Leaf spot, caused by *Cercospora beticola,* Sacc., has long been recognized as an important disease of the sugar beet (*Beta vulgaris* L.) in a large proportion of the sugar beet acreage east of the Rocky Mountains in the United States. Curly top, caused by the leafhopper-transmitted virus, *Ruga verrucosans* Carsner & Bennett, for many years has been a serious threat to the crop in much of the Western USA, especially west of the Rocky Mountains (6)[3]. The development of sugar beet varieties having some degree of resistance to leaf spot has given partial control of that disease east of the mountains, and the spectacular success in breeding curly top resistant varieties is well known.

Until recently, breeding work intended to produce varieties with combined resistance to leaf spot and curly top was not emphasized because of the fact that the sugar beet was not grown extensively in areas where both diseases were serious threats to the crop. In the last decade, however, the need for combined leaf spot and curly top resistance has increased substantially, especially because of expanded sugar beet production in areas where the crop is subject to both diseases. The most notable example of such a change occurred in the vicinity of Hereford, Texas, with the completion of the Merrill E. Shoup sugar factory by the Holly Sugar Corporation in 1964. Observation of the sugar beet crop in that area by the authors, for more than a decade, has shown that it is subject to severe attacks of leaf spot

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[3] Numbers in parentheses refer to literature cited.

and curly top, either separately or concurrently. Leaf spot exposure of economic significance occurs in most years, and recognition of its importance is indicated by the fact that about 94% of the entire sugar beet acreage in that area (approximately 30,000 acres) was sprayed for leaf spot control in 1965. Curly top exposure ranges from negligible in some seasons to extremely severe in others. An example of the latter occurred in 1954 when the curly top susceptible check in a variety test at Hereford yielded only 1/3 ton of roots per acre in contrast with a yield of 20 tons for the curly top resistant check[4]. Except as affected by spraying and the use of resistant varieties, both diseases were relatively severe in that vicinity in 1965.

The feasibility of combining moderate to high levels of leaf spot and curly top resistance in the same sugar beet variety was demonstrated in 1961[5] by the performance of the open-pollinated variety, SP 6051-0, a product of breeding work conducted jointly by the Crops Research Division at Beltsville, Maryland, and the New Mexico Agricultural Experiment Station at University Park, New Mexico[6]. Little, if any, commercial use has been made of SP 6051-0, but the combined levels of resistance in that variety represent a significant achievement.

Results of cooperative evaluation tests over a period of 5 years[7] and results of other studies pertaining to the inheritance of resistance to leaf spot[8] and curly top (7) have led us to the general conclusion that resistance of F_1 hybrids, to either disease, is approximately intermediate between the resistance of the two parents. Consequently, it seems clear that high levels of combined resistance to leaf spot and curly top should be expected in F_1 hybrids only when both parents are high in resistance to both diseases. One of the principal objectives of this article is to report on progress in the development of such material. Except where otherwise indicated, the results presented were obtained in 1965.

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[4] R. E. Finkner, et al., American Crystal Sugar Company. (Unpublished report).

[5] Gaskill, J. O., G. E. Coe, J. C. Overpeck, and A. M. Murphy. Development and evaluation of sugarbeet breeding material and varieties carrying resistance to leaf spot and curly top, 1961. Sugar Beet Research, 1961 Report (CR-4-62, Crops Research Division, A.R.S., U. S. Dept. of Agr.): 120-133. (Unpublished).

[6] Coe, G. E. Development of basic breeding material. Sugar Beet Research, 1961 Report (CR-4-62, Crops Research Division, A.R.S., U. S. Dept. of Agr.): 339-344. (Unpublished).

[7] Research reports, entitled "Development and evaluation of sugarbeet breeding material and varieties carrying resistance to leaf spot and curly top", for 1961 through 1965 by J. O. Gaskill and co-workers, presented in the following volumes of Sugarbeet Research: 1961 Report (pp. 120-133), 1962 Report (pp. 139-160), 1963 Report (pp. 179-210), 1964 Report (pp. 156-197), and 1965 Report (in press). (Unpublished).

[8] Gaskill, J. O., J. A. Elder, and LeRoy Powers. A preliminary report on inheritance of resistance to Cercospora leaf spot in sugar beets. Informal presentation at the 12th General Meeting, Am. Soc. Sugar Beet Technol., Denver, Colo., 1962. (Unpublished).

Cooperative Tests of LSR-CTR Varieties

Seed supplies of entries 1 through 7 (Table 1) were assembled at Fort Collins and distributed to cooperators who conducted and reported results for the evaluation tests listed below. Agronomic tests at two other locations were abandoned because of flood damage, poor stand, or other misfortunes.

Table 1.—Description of material in cooperative evaluation tests of LSR-CTR sugar beet varieties, 1965.

Entry no.	Fort Collins seed no.	Description and supplier[a]
1	Acc. 2634	SL (129 × 133) MS × SP 5822-0; monogerm; LSR-CTR; Farmers & Manufacturers Beet Sugar Association and West Coast Beet Seed Company (WC lot 4475).
2	Acc. 2635	CT 5 MS × SP 5822-0; monogerm; LSR-CTR; F. & M. and West Coast Beet Seed Company (WC lot 4494).
3	Acc. 2636	SL (129 × 133) MS × SP 6322-0; monogerm; LSR-CTR; F. & M. and West Coast Beet Seed Co. (WC lot 4567).
4	SP 641204HO1	FC (502/2 × 503) MS × FC 901; monogerm; LSR-CTR: Sugarbeet Investigations, Fort Collins, Colorado.
5	SP 641204HO3	FC (502/2 × 504) MS × FC 901; monogerm; LSR-CTD; Sugarbeet Investigations, Fort Collins, Colorado.
6	Acc. 2623	SP 5822-0; a multigerm, USDA variety, resistant to leaf spot and black root, developed for use in eastern sugarbeet areas; included in these cooperative tests as an LSR check; seed furnished by G. E. Coe, USDA, Beltsville, Maryland.
7	Acc. 2633	US H6; a multigerm, USDA variety, resistant to curly top and bolting, developed for use in Calif.; included in these tests as a CTR check; seed furnished by J. S. McFarlane, USDA, Salinas, Calif.
8		Local check; furnished by cooperator.
9		Local check; furnished by cooperator (occasional).

[a]The parental lines listed were developed by various USDA stations and may be described as follows:

Line	Seed type	Resistant to		
		Curly top	Leaf spot	Black root
CT 5	mono.	X		
SL 129 and 133	mono.	X		
SP 5822-0 and 6322-0	multi.		X	X
FC 502/2, 503, & 504	mono.		X	
FC 901	multi.	X	X (mod.)	

State	Locality	Type[a]	Cooperating agency and personnel
Calif.	Hamilton City	A	Holly Sugar Corp. (D. D. Dickenson & Alex Lange)
"	N. Tracy	A	Holly Sugar Corp. (D. D. Dickenson & Alex Lange)
Colo.	Fort Collins	A	U.S. Dept. of Agr. (J. A. Elder & J. O. Gaskill)
"	Rocky Ford	A	Amer. Crystal Sugar Co. (R. E. Finkner & staff)
Iowa	Mason City	A	Amer. Crystal Sugar Co. (R. E. Finkner & staff)
Kansas	Garden City	A	Amer. Crystal Sugar Co. (R. E. Finkner & staff)
"	Johnson	A	Amer. Crystal Sugar Co. (R. E. Finkner & staff)
"	Tribune	A	Kan. Agr. Exp. Station (R. E. Gwin, Jr.) and Nat'l. Sug. Mfg. Co. (G. E. Coupland and Henry Wolfe
Md.	Beltsville	A	U. S. Dept. of Agr. (G. E. Coe)
Minn.	Moorhead	A	Amer. Crystal Sugar Co. (R. E. Finkner & staff)
N. M.	Artesia	A	N. M. Agr. Exp. Station (W. J. Russell)
Okla.	Goodwell	A	Okla. Agr. Exp. Station (R. N. Ford, Roy Oswalt, R. S. Matlock, and Bill Ott)
Texas	Hereford	A	Holly Sug. Corp. (D. F. Peterson & Paul Scott)
Utah	Logan	O	U. S. Dept. of Agr. (C. L. Schneider)
"	Thatcher	O	U. S. Dept. of Agr. (A. M. Murphy)

[a] Type of test: A = agronomic; 0 = observational.

The agronomic tests varied considerably in plot size, experimental design, disease exposure, number of replications, etc. Certain of these details are given in the tables of results, but otherwise no attempt will be made to describe the individual tests in this article.

General summaries of harvest results of the agronomic tests, expressed as percent of the standard variety, SL (129 × 133) MS × SP 5822-0, are presented in Tables 2, 3, and 4. Leaf spot resistance comparisons in the agronomic tests at Fort Collins and Beltsville are shown in Table 5, and curly top resistance data, obtained in observational tests at Logan and Thatcher, are presented in Table 6. An indication of the degree of precision in the respective agronomic tests is given in the form of LSD values expressed as percent of the actual average yield or sucrose percentage of the standard variety. A striking varietal contrast under severe curly top exposure at Artesia, New Mexico, is shown in Figure 1.

Because of the wide range in the severity of leaf spot and curly top exposures at the various locations, average perform-

Table 2.—General summary of harvest results, cooperative agronomic evaluation tests of LSR-CTR sugar beet varieties, 1965; as percent of the standard variety, SL (129 × 133) MS × SP 5822-0.

Gross Sucrose Yield

Location	Diseases[a]	No. reps.	Entry no. 1	2	3	4	5	6	7	8[b]	9[b]	LSD[c] (.05)
(1) N. Tracy, Calif.		8	100	110	106	100	106	95	92	99		10
(2) Hamilton City, Calif.	LS-1	8	100	104	104	115	113	77	103	112		14
(3) Ft. Collins, Colo.	LS-3	9	100	97	107	119	113	94	94	104	94	5
(4) Rocky Ford, Colo.	LS-1, Rh-2	9	100	124	119	112	104	119	77	94	103	24
(5) Tribune, Kan.		9	100	113	106	103	109	99	106	106	106	12
(6) Garden City, Kan.		3	100	110	103	88	100	92	100	96	93	25
(7) Johnson, Kan.		3	100	101	120	105	102	94	100	90	95	18
(8) Goodwell, Okla.	CT-1, LS-1	10	100	106	103	106	114	101	88	128		13
(9) Hereford, Tex.	CT-3, LS-3	9	100	115	110	96	111	71	101	103	89	6
(10) Artesia, N. M.	CT-3+, LS-1	4	100	95	93	97	105	49	98	128	134	
(11) Moorhead, Minn.	LS-1?	9	100	103	113	105	111	96	120	109	94	15
(12) Mason City, Ia.	LS-1?, Rh-1?	9	100	106	100	97	112	95	126	94	110	24
(13) Beltsville, Md.	BR-1, LS-3	3	100	75	107	98	109	105	68	78		20
Average			100.0	104.5	107.0	103.2	108.4	91.3	97.9	103.2		

[a] Disease exposure considered sufficient to affect harvest results appreciably: BR = black root *(Aphanomyces cochlioides);* CT = curly top (virus); LS = leaf spot (*Cercospora beticola*); Rh = Rhizoctonia root rot. Estimated severity of disease exposure: 1 = mild; 2 = moderate; 3 = severe.

[b] The local checks, entries 8 and 9, were as follows, respectively (location numbers in parentheses): (1) HH 8; (2) HH 9; (3) GW 674-56C and SL (126 × 128) MS × SP 5822-0; (4) Am 2 Mono and Am 2 Multi; (5) SL (126 × 128) MS × SP 5822-0 and G.W.S. Co. monogerm; (6) Am 2 Mono and Am 2 Multi; (7) same as (6); (8) HH 10; (9) HH 10 and HH 12; (10) HH 10 and Holly 3227-05; (11) Am 3 S Mono and Am 3 N Multi; (12) Am 3 S Mono and Am 3 S Multi; (13) SP 64100-05.

[c] LSD (.05) expressed as percent of the gross sucrose yield of the standard variety.

Table 3.—General summary of harvest results, cooperative agronomic evaluation tests of LSR-CTR sugar beet varieties, 1965; as percent of the standard variety, SL (129 × 133) MS × SP 5822-0.

Root Yield

Location	Diseases[a]	No. reps.	Entry no. 1	2	3	4	5	6	7	8[b]	9[b]	LSD[c] (.05)
(1) N. Tracy, Calif.		8	100	113	109	96	104	99	97	100		9
(2) Hamilton City, Calif.	LS-1	8	100	110	107	115	108	80	107	122		11
(3) Ft. Collins, Colo.	LS-3	9	100	99	107	113	109	96	98	104	94	5
(4) Rocky Ford, Colo.	LS-1, Rh-2	9	100	126	123	109	106	119	84	100	102	24
(5) Tribune, Kan.		9	100	112	106	100	107	98	108	103	100	10
(6) Garden City, Kan.		3	100	106	93	83	90	88	96	89	86	22
(7) Johnson, Kan.		3	100	102	116	106	100	98	100	91	93	16
(8) Goodwell, Okla.	CT-1. LS-1	10	100	115	107	107	113	95	101	127		9
(9) Hereford, Tex.	CT-3, LS-3	9	100	115	109	94	110	72	104	105	91	6
(10) Artesia, N. M.	CT-3+, LS-1	4	100	92	101	93	105	42	134	114	119	23
(11) Moorhead, Minn.	LS-1?	9	100	106	112	100	109	101	121	106	97	15
(12) Mason City, Ia.	LS-1?, Rh-1?	9	100	101	96	95	104	93	132	90	113	23
(13) Beltsville, Md.	BR-1, LS-3	3	100	82	110	99	115	106	81	91		22
Average			100.0	106.3	107.4	100.8	106.2	91.3	104.8	103.2		

[a] Disease exposure considered sufficient to affect harvest results appreciably: BR = black root (*Aphanomyces cochlioides*); CT = curly top (virus); LS = leaf spot (*Cercospora beticola*); Rh = Rhizoctonia root rot. Estimated severity of disease exposure: 1 = mild; 2 = moderate; 3 = severe.

[b] The local checks, entries 8 and 9, were as follows, respectively (location numbers in parentheses): (1) HH 8; (2) HH 9; (3) GW 674-56C and SL (126 × 128) MS × SP 5822-0; (4) Am 2 Mono and Am 2 Multi; (5) SL (126 × 128) MS × SP 5822-0 and G.W.S. Co. monogerm; (6) Am 2 Mono and Am 2 Multi; (7) same as (6); (8) HH 10; (9) HH 10 and HH 12; (10) HH 10 and Holly 3227-05; (11) Am 3 S Mono and Am 3 N Multi; (12) Am 3 S Mono and Am 3 S Multi; (13) SP 64100-05.

[c] LSD (.05) expressed as percent of the root yield of the standard variety.

Table 4.—General summary of harvest results, cooperative agronomic evaluation tests of LSR-CTR sugar beet varieties, 1965; as percent of the standard variety, SL (129 × 133) MS × SP 5822-0.

Sucrose Percentage

Location	Diseases[a]	No. reps.	Entry no. 1	2	3	4	5	6	7	8[b]	9[b]	LSD[c] (.05)
(1) N. Tracy, Calif.		8	100	98	97	104	102	97	95	99		5
(2) Hamilton City, Calif.	LS-1	8	100	95	97	100	104	96	96	92		8
(3) Ft. Collins, Colo.	LS-3	9	100	99	101	106	104	98	96	100	100	1
(4) Rocky Ford, Colo.	LS-1, Rh-2	9	100	98	97	103	99	100	92	94	101	5
(5) Tribune, Kan.		9	100	101	101	103	102	102	98	103	106	4
(6) Garden City, Kan.		3	100	103	110	106	111	105	105	109	108	9
(7) Johnson, Kan.		3	100	99	104	99	102	96	100	100	102	9
(8) Goodwell, Okla.	CT-1, LS-1	10	100	92	96	99	101	106	87	101		9
(9) Hereford, Tex.	CT-3, LS-3	9	100	100	101	102	101	99	97	98	98	2
(10) Artesia, N. M.	CT-3+, LS-1	4	100	103	92	105	101	118	73	112	113	13
(11) Moorhead, Minn.	LS-1?	9	100	97	101	105	102	96	99	103	96	4
(12) Mason City, Ia.	LS-1?, Rh-1?	9	100	102	104	102	108	102	95	104	97	7
(13) Beltsville, Md.	BR-1, LS-3	3	100	93	97	99	96	99	84	86		4
Average			100.0	98.5	99.8	102.5	102.5	101.1	93.6	100.1		

[a] Disease exposure considered sufficient to affect harvest results appreciably: BR = black root *(Aphanomyces cochlioides)*; CT = curly top (virus); LS = leaf spot (*Cercospora beticola*); Rh = Rhizoctonia root rot. Estimated severity of disease exposure: 1 = mild; 2 = moderate; 3 = severe.

[b] The local checks, entries 8 and 9, were as follows, respectively (location numbers in parentheses): (1) HH 8; (2) HH 9; (3) GW 674-56C and SL (126 × 128) MS × SP 5822-0; (4) Am 2 Mono and Am 2 Multi; (5) SL (126 × 128) MS × SP 5822-0 and G.W.S. Co. monogerm; (6) Am 2 Mono and Am 2 Multi; (7) same as (6); (8) HH 10; (9) HH 10 and HH 12; (10) HH 10 and Holly 3227-05; (11) Am 3 S Mono and Am 3 N Multi; (12) Am 3 S Mono and Am 3 S Multi; (13) SP 64100-05.

[c] LSD (.05) expressed as percent of the sucrose percentage of the standard variety.

Table 5.—Leaf spot resistance comparisons of LSR-CTR sugar beet varieties, Fort Collins, Colorado, and Beltsville, Maryland, 1965[a].

Description	Ft. Collins seed no.	Entry no.	Leaf spot grades[b]				
			Ft. Collins[c]		Beltsville[d]		
			8/23	9/1	8/6	8/12	9/4
SL (129 × 133) MS × SP 5822-0	Acc. 2634	1	3.9	4.3	3.3	3.5	4.6
CT 5 MS × SP 5822-0	Acc. 2635	2	4.3	4.9	4.0	4.0	4.6
SL (129 × 133) MS × SP 6322-0	Acc. 2636	3	3.7	4.3	3.3	3.4	4.6
FC (502/2 × 503) MS × FC 901	SP 641204HO1	4	2.7	3.2	3.1	3.1	4.1
FC (502/2 × 504) MS × FC 901	SP 641204HO3	5	2.8	3.2	2.8	3.1	4.2
SP 5822-0; LSR check	Acc. 2623	6	2.1	2.2	2.6	2.8	3.9
US H6; CTR check	Acc. 2633	7	5.7	6.2	4.3	4.5	5.3
GW 674-56C	Acc. 2168		2.9	3.9			
SL (126 × 128) MS × SP 5822-0	Acc. 2642		4.2	4.8			
SP 64100-05					3.6	3.7	5.2
SP 6322-0					2.0	2.3	3.2

[a] Leaf spot exposure was intensified artificially.
[b] Approximate basis of leaf spot grades: 0 = no leaf spot; 10 = complete defoliation.
[c] Plots 2 rows × 20′; 9 × 9 Latin Square design.
[d] Plots 4 rows × 20′; 3 replications; randomized block design.

Figure 1.—Comparison of sugar beet varieties under severe curly top exposure, Artesia, N. M., September 17, 1965; plots 4 rows (2 beds) wide and 22 ft. long. Left, SP 5822-0; right, FC (502/2 × 503) MS × FC 901.

Table 6.—Curly top resistance comparisons of LSR-CTR sugar beet varieties at Thatcher and Logan, Utah, 1965.

Description	Fort Collins seed no.	Entry no.	Thatcher (field plots)[a] C. T. incidence 9/15	Thatcher C. T. grade Actual 10/1[c]	Thatcher C. T. grade % of US 41	Thatcher Plants per 100′	Logan (greenhouse)[b] C. T. incidence	Logan C. T. grade Actual[c]	Logan C. T. grade % of US 41
			%			No.	%		
SL (129 × 133) MS × SP 5822-0	Acc. 2634	1	76.9	4.0	133	100	95	5.7	130
CT 5 MS × SP 5822-0	Acc. 2635	2	76.6	4.0	133	98	100	6.2	141
SL (129 × 133) MS × SP 6322-0	Acc. 2636	3	74.8	4.0	133	101	95	5.4	123
FC (502/2 × 503) MS × FC 901	SP 641204HO1	4	82.0	4.5	150	102	95	5.5	125
FC (502/2 × 504) MS × FC 901	SP 641204HO3	5	78.2	4.0	133	106	95	5.5	125
SP 5822-0; LSR check	Acc. 2623	6	95.2	6.0	200	104	95	7.1	161
US H6; CTR check	Acc. 2633	7	62.3	3.0	100	102	80	4.5	102
US 33			82.8	4.8	160	86	95	5.5	125
US 41			47.0	3.0	100	101	85	4.4	100

[a] Plots 2 rows × 50′; each entry occurred in 2 replications: curly top exposure was intensified artificially.

[b] Seedling technique; curly top virus culture A1A; 20 plants per variety; 2 caged leafhoppers per plant.

[c] Basis of curly top grades: 0 = healthy; 9 = death due to curly top. In field plots, the grade represented the combined effects of curly top incidence and reaction of plants to infection. In the greenhouse, plants without curly top symptoms were disregarded.

ance figures for the LSR check (SP 5822-0) and the CTR check (US H6) mean little. Examination of the averages for certain other entries reveals the following important trends or relationships:

1. With SL (129 × 133) MS serving as the female, SP 6322-0 was substantially superior to SP 5822-0 for use as the pollinator. The average gross sucrose yield for entry no. 3 [SL (129 × 133) MS × SP 6322-0] was 107.0 percent of that of entry no. 1 [SL (129 × 133) MS × SP 5822-0], and there was essentially no difference in average sucrose percentage.
2. The outstanding hybrid in the entire series, in yield of gross sucrose, was entry no. 5 [FC (502/2 × 504) MS × FC 901], and its average sucrose percentage also was relatively high. The average gross sucrose yield and sucrose percentage for entry no. 5 were 108.4 and 102.5% of the corresponding averages for the standard variety, entry no. 1. Entry no. 3, described above, was the only close competitor of no. 5 in gross sucrose yield, but it was no better than the standard variety in sucrose percentage. Thus it was concluded that, under the array of conditions represented by these tests, FC (502/2 × 504) MS × FC 901 was substantially superior to the other LSR-CTR varieties (entries 1 through 4) in its combination of abilities to produce high gross sucrose yield with high sucrose percentage.
3. To put the above comparisons in proper perspective, it should be noted that the average gross sucrose yield and average sucrose percentage for entry no. 8 (local check), expressed as percent of the corresponding averages for entry no. 1 (standard variety), were 103.2 and 100.1, respectively. Furthermore, it should be recalled (a) that the current standard variety, SL (129 × 133) MS × SP 5822-0, exceeded SL 126 MS × SP 5460-0, in the 1964 cooperative test series, by an average of about 3% in gross sucrose yield[9]; and (b) that the latter hybrid exceeded SL 122 MS × SP 5460-0 by 11% in gross sucrose yield in both the 1962 and 1963 cooperative test series[10].

[9] Gaskill, J. O., A. M. Murphy, C. L. Schneider, G. E. Coe, and J. A. Elder. Development and evaluation of sugarbeet breeding material and varieties carrying resistance to leaf spot and curly top, 1964. Sugarbeet Research, 1964 Report (CR-4-65, Crops Research Division, A.R.S., U. S. Dept. of Agr.): 156-197. (Unpublished).

[10] Research reports, entitled "Development and evaluation of sugarbeet breeding material and varieties carrying resistance to leaf spot and curly top", by J. O. Gaskill and coworkers, presented in the following volumes of Sugarbeet Research: 1962 Report (pp. 139-160), and 1963 Report (pp. 179-210). (Unpublished).

As shown in Table 5, entries 1, 2, and 3 were approximately intermediate between the resistant and susceptible checks (entries 6 and 7) in leaf spot resistance. Each of the entries, 1, 2, and 3, was an F_1 hybrid of LSR $\times$ CTR material—i.e., leaf spot resistant $\times$ leaf spot susceptible—and its level of leaf spot resistance was about as expected. Entries 4 and 5 (F_1 hybrids of LSR $\times$ LSR-CTR material) were consistently better than entries 1, 2, and 3 in leaf spot resistance. Although not large, these differences are considered meaningful.

All of the entries, 1 through 5, were approximately intermediate between entries 6 and 7 in curly top resistance (Table 6). Since each of the entries, 1 through 5, received its curly top resistance from either the male or the female parent, but not both, an intermediate level of resistance in the hybrids was to be expected.

Development and Evaluation of LSR-CTR, Monogerm, Type-0, Inbred Lines

Basic breeding material utilized for the development of LSR-CTR, monogerm, type-0, inbred lines consisted of (a) curly top resistant lines, of both multigerm and monogerm types, furnished by the late Dr. F. V. Owen of the Crops Research Division, Salt Lake City, Utah; and (b) leaf spot resistant lines from the Division's breeding projects at Fort Collins, Colorado, and Beltsville, Maryland. The monogerm gene, where it occurred in this material, had been derived initially from SLC 101 (9). Because of earlier success in transferring leaf spot resistance by means of the backcross method (1), this technique was used as the principal tool for combining resistance to leaf spot and curly top. In this undertaking, the multigerm line, US 201, served as the nonrecurrent parent and the source of leaf spot resistance. Curly top resistant lines served as the recurrent parental type. Of the latter material, multigerm lines were used in matings to produce the F_1 and B_1 generations, and the monogerm, type-0, self-fertile line, SLC 122-0, was used to produce the B_2 generation. Monogerm segregants, selected from the open-pollinated increase of the B_2, were placed in two groups for seed production as follows: (a) SP 611100-0, a seed lot having cytoplasm derived from SLC 122-0; and (b) SP 611101-0, a seed lot having cytoplasm derived from the multigerm, curly top resistant line, SL 202. SP 611100-0 and SP 611101-0 were produced in the greenhouse by means of induced seedlings (2, 4). Selection for leaf spot resistance was performed in the field at Fort Collins in the F_1 and B_1 generations, and subsequently in populations of SP 611100-0 and SP 611101-0.

Leaf spot resistant individuals, selected from populations of SP 611100-0, SP 611101-0, etc., were mated with cytoplasmic male-sterile (CMS) material, for type-0 indexing purposes, and selfed. In contrast with the method reported by Owen (8) in which a CMS annual was used, the CMS material employed for the index matings in this as well as an earlier project (3) was biennial in character. Flowering of the hybrids, required for anther classification, was obtained promptly by means of the seedling induction technique (2,4).

Observational Screening of Monogerm, Type-0 Lines for Leaf Spot and Curly Top Resistance

An essential step in the development of LSR-CTR, type-0, inbred lines, is the observational evaluation of S_1 and S_2 lines for resistance to leaf spot and curly top promptly after indexing. A portion of the selfed seed obtained from each of 33 monogerm plants that had been indexed and rated type-0 or nearly so, was used in 1965 for curly top resistance evaluation in the greenhouse at Logan, Utah, and part was used for leaf spot resistance appraisal in field plots at Fort Collins, Colorado. The greenhouse technique[11] was a modification of a method devised by Giddings (5). Additional details regarding techniques are given in Table 7.

The results of the leaf spot and curly top resistance comparisons are presented in Table 7. The superior resistance to both diseases, shown for three of the four sub-lines of FC 601 (entries 328-334), is of special interest. In addition to the FC 601 material, 11 lines, tentatively classed as type-0 or near-type-0, were at least equal to SP 5481-0 in leaf spot resistance and to US 41 in curly top resistance.

It should be noted that the four S_1 lines obtained directly from SP 611227-(001) were given average curly top grades ranging from 108 to 123. In contrast with those lines, one of the seven S_1 lines obtained from SP 631103-0 was given an average grade of 104 and the other six ranged from 88 to 98. SP 611227-(001) presumably is segregating for curly top resistance. Apparently, the greenhouse selection of curly top resistant seedlings in that population by C. W. Bennett, giving rise to SP 631103-0, may have improved the general level of resistance of the material.

[11] Schneider, C. L. Greenhouse tests of curly top resistance. Sugarbeet Research. 1962 Report (CR-4-63, Crops Research Division, A.R.S., U. S. Dept. of Agr.): 85-89. (Unpublished).

Table 7.—Preliminary evaluation of leaf spot and curly top resistance of monogerm, type-0 and near-type-0, inbred lines of sugar beets, Fort Collins, Colo., and Logan, Utah, 1965.

Description and/or source	Immediate parent	Strain no. (seed no.)	No. gen. self	Pol.[1] rating	0-[2] rating	Ft. Collins exp. no. 6A[3]					Logan greenhouse[4]		
						Entry no.	No. of plots	Leaf spot[5] 8/25	Leaf spot[5] 9/3	Vig.[6] 8/9-10	Code no.	No. infect. plants	Curly[7] top
SP 611100-0	SP 622027sl	SP 642009sl	2	4	95/0	301	1	0.5	0.5	5.0	65-1	18	110
" "	" "	SP 642010sl	2	4	92/0	303	2	1.8	1.8	5.0	65-2	20	104
" "	SP 622075sl	SP 642027sl	2	5	96/0	307	2	1.8	2.5	6.0	65-4	20	75
" "	SP 622105sl	SP 642087sl	2	5	95/5	313	2	2.8	3.5	6.5	65-5	19	102
SP "	SP 622107sl	SP 642094sl	2	5	90/0	317	1	1.0	2.0	5.0	65-6	17	133
" "	" "	SP 642101sl	2	5	95/0	319	2	1.0	1.0	5.0	65-7	20	112
" "	" "	SP 642107sl	2	5	90/0	321	1	3.0	4.0	5.0	65-8	19	112
" "	SP 622112sl	SP 642063sl	2	4	95/0	322	2	2.3	3.0	5.0	65-9	17	81
" "	" "	SP 642064sl	2	5	100/0	324	2	1.8	2.5	5.0	65-10	18	117
" "	" "	SP 642072sl	2	5	95/0	326	2	1.5	2.3	4.5	65-11	17	106
SP 611101-0	SP 622071sl[8]	SP 642032sl	2	6	100/0	328	1	1.5	1.5	6.0	65-12	17	89
" "	" "	SP 642050sl	2	5	100/0	330	1	2.0	3.0	5.0	65-13	18	100
" "	" "	SP 642056sl	2	4	100/0	332	2	1.8	1.8	5.5	65-14	17	80
" "	" "	SP 642065sl	2	3	100/0	334	2	1.3	2.3	5.0	65-15	19	93
" "	SP 622076sl	SP 642102sl	2	4	95/0	340	2	4.0	4.0	5.5	65-16	19	106
" "	SP 622101sl	SP 642049sl	2	5	100/0	342	1	1.5	2.0	6.0	65-17	20	100
" "	" "	SP 642090sl	2	6	100/0	344	1	1.5	2.0	5.0	65-18	18	104
SP 611100-0	SP 631101-0A	SP 642044sl	1	6	96/0	353	1	1.5	3.0	5.0	65-20	20	131
" "	" "	SP 642054sl	1	6	92/0	357	2	1.0	2.0	6.5	65-21	19	92
" "	" "	SP 642082sl	1	6	100/0	361	2	1.0	1.0	6.5	65-22	16	90
" "	" "	SP 642089sl	1	6	92/0	363	2	1.8	2.0	6.5	65-23	18	98
" "	" "	SP 642093sl	1	3	88/0	367	1	2.0	2.5	7.0	65-24	16	96
LSR-CTR pool[9]	SP 611227-(001)	SP 642017sl	1	5	88/0	369	2	2.5	3.3	5.0	65-25	20	110
" " "	" "	SP 642028sl	1	6	100/0	371	2	2.5	4.0	6.0	65-26	19	123

" " "	" "	SP 642052sl	1	6	96/0	375	2	6.0	5.0	5.0	65-27	20	108
" " "	" "	SP 642077sl	1	6	100/0	377	2	1.0	1.5	6.0	65-28	9	110
SP 611227-(001)	SP 631103-0[10]	SP 642004sl	1	5	91/0	379	2	3.5	4.5	6.0	65-29	12	88
" "	" "	SP 642033sl	1	5	100/0	384	2	2.5	2.5	6.0	65-31	10	104
" "	" "	SP 642047sl	1	6	92/0	390	2	1.8	1.8	5.5	65-32	12	90
" "	" "	SP 642079sl	1	6	91/0	392	2	2.0	2.3	6.5	65-33	10	98
" "	" "	SP 642085sl	1	6	96/0	395	2	3.3	3.5	5.0	65-34	8	96
" "	" "	SP 642096sl	1	6	100/0	398	2	2.0	2.0	5.5	65-35	11	96
" "	" "	SP 642097sl	1	6	96/4	400	2	2.5	2.5	6.5	65-36	9	96
SP 5481-0		Acc. 2483				404	9	2.1	3.1	6.9	65-42	15	142
SP 6051-0		SP 631210HO									65-43	16	102

[1] Quantity of pollen shed by the individual plant that was selfed to produce the indicated seed no. Basis of grades: 1-7 in ascending order of abundance (ordinary, open-pollinated, commercial variety usually rated 6 or 7).

[2] Pertains to the indexing population (at least 20 plants); left number is percentage classed as male sterile; right number is percentage classed as male fertile; percentage unaccounted for, if any, represents intermediate types.

[3] Field plots on Hospital Farm, Ft. Collins, Colo.; inoculation and frequent sprinkling used to promote leaf spot development; plots 1 row x 20', flanked uniformly by rows of a leaf spot susceptible strain.

[4] Curly top resistance evaluation at Logan, Utah, using greenhouse seedling technique with Logan culture A1A of the curly top virus, 20 plants for each code no., and 2 caged leafhoppers per plant.

[5] Leaf spot grades (J. A. Elder): 0 = no leaf spot; 10 = complete defoliation.

[6] Foliage vigor (J. A. Elder): Larger no. = greater vigor.

[7] Curly top severity (C. L. Schneider). The plants were classified individually on a scale of 0 - 9 (0 = no symptoms, 9 = dead). Plants without curly top symptoms were disregarded. Results for plants with curly top symptoms were averaged by strains, and the averages were converted to percent of US 41. Thus, values less than 100 (shown above) indicate less curly top injury than in US 41, and values greater than 100 indicate more curly top injury than in US 41.

[8] FC 601.

[9] Miscellaneous F_1 hybrids (LSR × CTR), without US 201 blood, were allowed to interpollinate to produce the seed lot designated SP 611227-(001).

[10] Seed produced at Ft. Collins, using plants selected for curly top resistance, while in the early seedling stage, by C. W. Bennett, Salinas, California.

Agronomic Evaluation of Monogerm, Type-0 Lines

Several monogerm, type-0 or near-type-0, self-fertile, S_1 or S_2 inbred lines, thought to possess some resistance to both leaf spot and curly top, were evaluated in the leaf spot field at Fort Collins and under curly top conditions at Thatcher, Utah. The techniques employed at Thatcher are described briefly in the tables of results.

The tests at Fort Collins were of two types. In one (Experiment 5A), the inbred lines themselves were compared with check material by using a modified randomized-block design with three replications. Plots were four rows wide and 20 feet long, and the two inner rows were harvested for yield and sucrose determinations. Yield data for the inbred lines are considered to have relatively little meaning, but sucrose percentages may be indicative of their potential value.

The other Fort Collins test (Experiment 10A) was designed to appraise the general combining ability of the lines by using the USR-CTR variety, FC 901, as a common parent. Since fairly representative male-sterile equivalents of the inbreds were not yet available, hybridizations had been made by using Mendelian male-sterile (aa) segregants in FC 901 as the female parent in each of a series of matings with the inbred lines. The resulting hybrids (seed harvested in the greenhouse in the spring of 1965) were compared with check material in Experiment 10A by using a randomized-block design, 1-row $\times$ 20-ft. plots, and 9 replications. Both experiments, 5A and 10A, were planted rather late (May 10).

The results of Experiments 5A and 10A are presented in Tables 8 and 9, respectively, together with the curly top resistance data from Thatcher. Three of the type-0 lines (Table 8) were better than SP 5481-0 in leaf spot resistance and approached or equaled US 41 in curly top resistance. Those lines are SP 632028sl, FC 601, and SP 632090sl. The last two were rather low in sucrose percentage, especially SP 632090sl.

The results presented in Table 9 agree with those in Table 8 in showing relatively high leaf spot resistance and high curly top resistance (at least equal to US 41) for the hybrids involving the three inbreds named in the preceding paragraph. In line with the performance of SP 632090sl as an inbred, the hybrid of SP 632090sl was significantly lower in sucrose percentage than the hybrids of SP 632028sl and FC 601. Each of the last mentioned two hybrids (a) approximately equaled FC (502/2 $\times$ 504) MS $\times$ FC 901 in yield of roots and gross sucrose and in sucrose

Table 8.—Preliminary agronomic evaluation of monogerm, type-o, inbred lines of sugar beet, Fort Collins, Colo., and Thatcher, Utah, 1965.

Description	Fort Collins seed no.	Fort Collins, Colo. (Exp. 5A), 3-plot averages)							Thatcher, Utah[c]		
		Acre yield			Leaf spot[a]				Curly top		
		Gross suc.	Roots	Sucrose	8/23	9/1	Vig.[b] 8/12	Plants per 100′	% 9/15	Grade[d] 10/1	Plants per 100′
		Lbs	Tons	%				No.			No.
I. Monogerm, type-0 (±) LSR-CTR inbred lines											
SP 632028sl (S_1 from SP 611101-0)	SP 651151HOA	2619	8.83	14.83	2.2	3.5	6.0	128	36	3.0	88
SP 632090sl (S_1 from SP 611101-0)	SP 651152HO	2199	8.33	13.20	1.7	1.8	6.3	125	55	3.0	88
SP 612070sl (S_2 from US 201× SLC 91)	SP 651154HO[e]								67	6.0	42
SP 622027sl (S_1 from SP 611100-0)	SP 641155HOA								79	5.0	84
SP 622027sl; SP 641155HOA	SP 651155HOA	1506	5.31	14.22	1.5	2.2	5.0	125	85	6.0	54
FC 601 (SP 622071sl; S_1 from SP 611101-0)	SP 641156HOA								79	5.0	84
FC 601 SP 641156HOA	SP 651156HOA	1908	7.12	13.40	1.2	1.2	5.3	120	39	3.5	66
II. Checks											
FC 502/2 (mm, type-0, LSR inbred)	SP 641207HO	3112	9.59	16.23	1.0	1.8	5.3	131			
US 201 (MM)	SP 581001-0	1727	6.00	14.38	1.0	1.2	6.0	124			
Synthetic Check (MM)	Acc. 2269	2267	8.83	12.83	7.2	7.2	6.7	122			
SP 5481-0 (MM)	Acc. 2483	2361	8.58	13.73	4.5	4.3	7.0	118	84	5.5	106
SP 6051-0 (MM)	SP 631210HO								63	4.0	94
US 33									84	4.8	86
US 41									45	3.3	98

[a] Leaf spot grades (J. A. Elder): 0 = no leaf spot; 10 = complete defoliation.

[b] Foliage vigor (J. A. Elder): Larger no. = greater vigor.

[c] Results at Thatcher were based on a minimum of one 50′ row for each line.

[d] Curly top grades (A. M. Murphy): 0 = healthy; 9 = death due to curly top.

[e] The preceding generation (SP 631170HO), evaluated under leaf spot conditions in 1964, was found to have excellent leaf spot resistance and acceptable sucrose percentage, root size, and foliage vigor.

Table 9.—Agronomic evaluation of experimental, LSR-CTR, sugar beet hybrids, Fort Collins, Colorado, and Thatcher, Utah, 1965.

Description[a]	Fort Collins seed no.	Fort Collins, Colo. (Exp. 10A) 9-plot avs.						Thatcher, Utah[c]		
		Acre yield			Leaf spot[b]		Plants per 100'	Curly top		Plants per 100'
		Gross sucr.	Roots	Sucrose	8/23	9/1		% 9/15	Grade[d] 10/1	
		Lbs	Tons	%			No.			No.
FC 901 aa × SP 632028sl mm	SP 651151HO2	3369	11.10	15.16	2.7	2.8	117	64	3.0	116
FC 901 aa × SP 632090sl mm	SP 651152HO2	3073	10.78	14.24	2.4	2.4	114	62	3.0	110
FC 901 aa × SP 612070sl mm	SP 651154HO2	2720	8.97	15.19	2.8	2.9	113	83	5.0	94
FC 901 aa × SP 622027sl mm	SP 651155HO2	2640	9.04	14.60	3.4	3.9	113	55	4.0	106
FC 901 aa × FC 601 (SP 622071sl) mm	SP 651156HO2	3175	10.49	15.14	2.3	2.4	120	51	3.0	105
FC (502/2 × 503) mm MS × FC 901	SP 641204HO1	3398	11.02	15.42	2.9	3.3	111	74	4.0	95
FC (502/2 × 504) mm MS × FC 901	SP 641204HO3	3221	10.62	15.16	3.1	3.1	115	74	4.0	89
SL (129 × 133) mm MS × SP 5822-0	Acc. 2634	2434	8.52	14.23	4.2	4.5	114	77	4.0	100
SP 5481-0	Acc. 2483							84	5.5	106
SP 6051-0	SP 631210HO							63	4.0	94
US 33								84	4.8	86
US 41								45	3.3	98
General mean		3004	10.07	14.90	3.0	3.2	115			
S. E. of var. mean		94.30	0.3123	0.1179	0.17	0.17	3.02			
S. E. of var. mean as % of gen. mean		3.14	3.10	0.79	5.87	5.48	2.64			
L.S.D. (.05)		267	0.88	0.33	0.5	0.5	9			
F (varieties)		14.58**	11.14**	15.61**	11.64**	17.23**	0.83			

[a] Lines are multigermn (MM) except where otherwise indicated. MS and aa denote cytoplasmic and Mendelian types of male sterility, respectively.

[b] Leaf spot grades (J. A. Elder): 0 = no leaf spot; 10 = complete defoliation.

[c] Results at Thatcher were based on a minimum of one (but mostly two or more) 50' rows for each variety or hybrid.

[d] Curly top grades (A. M. Murphy): 0 = healthy; 9 = death due to curly top.

** F exceeds the 1% point.

percentage; and (b) exceeded the standard variety, SL (129 × 133) MS × SP 5822-0, by highly significant amounts in each of those three attributes. Evaluation of the type-0 character of SP 632028sl and FC 601 has not been completed, but each line appears to be bonafide type-0 or nearly so.

As shown in Table 8, SP 632028sl, FC 601, and SP 632090sl were derived from the basic line, SP 611101-0. As previously indicated, this and another basic line shown in Table 8 (SP 611100-0) are segregating, monogerm populations, developed by means of a backcrossing program in which curly top resistant material served as the recurrent parental type and US 201, the nonrecurrent parent, was the source of leaf spot resistance. The LSR-CTR, multigerm line, FC 901, is a product of a similar backcrossing program with the same nonrecurrent parent. It was developed primarily for use as a source for the selection of superior pollinators. As a shortcut for preliminary evaluation of certain type-0 lines, however, FC 901 was used as the female parent in the hybridizations shown in Table 9.

The relatively high yields of roots and gross sucrose, shown for three of the hybrids having FC 901 as the female parent (Table 9), are of special significance in light of the fact that the male and female parents of each hybrid were related at least as indicated by the following: (a) their leaf spot resistance was derived from the same source, US 201; and (b) the curly top resistant material, used in the production of the F_1 and B_1 generations in the backcrossing program leading to the development of the inbreds, was nearly identical to that used at the corresponding steps in the development of FC 901. The curly top resistant lines, used to produce the final backcross (B_2) in the two backcrossing programs (SLC 122-0 and SL 932, respectively), were presumed to be only distantly related.

Summary

1. Cooperative evaluation tests of a set of five, monogerm, hybrid, sugar beet varieties, carrying some degree of resistance or tolerance to both leaf spot and curly top (so-called "LSR-CTR" varieties), were conducted by various agencies at 15 locations in 10 states in 1965. At two locations, disease resistance, only, was evaluated. At the other 13 locations, the tests were agronomic in character. Harvest results, in terms of root and gross sucrose yield and sucrose percentage, were expressed as percentages of the corresponding values for the standard variety, SL (129 × 133) MS × SP 5822-0. High lights of the results follow:

a. With SL (129 × 133) MS serving as the female, SP 6322-0 was substantially superior to SP 5822-0 for use as a pollinator. With the average gross sucrose yield of SL (129 × 133) MS × SP 5822-0 expressed as 100, the gross sucrose yield of SL (129 × 133) MS × SP 6322-0 was 107.0. Differences between the two hybrids in sucrose percentage and in resistance to leaf spot and curly top were negligible.

b. The outstanding hybrid in the entire series, in yield of gross sucrose, was FC (502/2 × 504) MS × FC 901, and its sucrose percentage also was relatively high. The average gross sucrose yield and sucrose percentage, for that hybrid, as percent of standard, were 108.4 and 102.5. FC (502/2 × 504) MS × FC 901 was about equal to the standard variety in curly top resistance and higher than the standard variety in leaf spot resistance. Average gross sucrose yield and sucrose percentage for the local check (entry 8), as percent of standard, were 103.2 and 100.1, respectively.

2. Backcross programs in which US 201 served as the nonrecurrent parent and curly top resistant material served as the recurrent parental type have led to the development of the following:

a. FC 901, a multigerm variety with high resistance to curly top and moderate resistance to leaf spot; considered a promising source for the selection of superior lines for use as pollinators.

b. Basic, LSR-CTR, monogerm material (SP 611100-0 and SP 611101-0), segregating for type-0. Three type-0, or near-type-0, S_1 inbred lines (SP 632028sl, FC 601, and SP 632090sl), derived from SP 611101-0, were crossed with FC 901, using the Mendelian male-sterile (aa) phase of the latter as the female parent. Each of the hybrids, FC 901 aa × SP 632028sl and FC 901 aa × FC 601, in comparison with FC (502/2 × 504) MS × FC 901, was: 1) about the same in yield of roots and gross sucrose and in sucrose percentage, under leaf spot conditions at Fort Collins; 2) at least as high in leaf spot resistance; and 3) higher in curly top resistance, being about the same as the curly top resistant check, US 41.

3. The results of this study showed conclusively: (a) that the backcross method is a useful tool for combining leaf spot and curly top resistance; and (b) that US 201 is suitable for use in such a program as the nonrecurrent parent and the source of leaf spot resistance.

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