Occurrence of Yellows Resistance in the Sugar Beet With an Appraisal of the Opportunities for Developing Resistant Varieties

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Introduction

Beet yellows is a virus disease which occurs in nearly all countries where the sugar beet is grown. In the United States the disease causes serious losses in California and in the Salt River Valley of Arizona. Bennett, Price, and McFarlane (3)[3] found that beet yellows reduced root yields from 13.8 to 53.0% and sucrose content from 0.4 to 2.2 percentage points. Seed yields of commercial sugar beet varieties were reduced as much as 34.9% in Arizona (7) and 44.6% at Salinas, California (2).

Beet western yellows (radish yellows) described by Duffus (4) also causes a yellowing of beets which is difficult to distinguish from yellowing induced by the less virulent strains of beet-yellows virus. Duffus (5) found that western yellows caused losses which were additive to losses produced by beet yellows when the 2 diseases occurred simultaneously. Western yellows is present in most of the beet-producing areas of western United States and in most of these areas more beets are affected by this disease than by beet yellows.

Progress in breeding for resistance to beet yellows has been reported from Europe. In the Netherlands, breeding work has been in progress since 1948 and selections have been developed in which yield reductions do not exceed 14 to 16% (8). Information is not available on resistance of these selections to western yellows.

Nine wild species of *Beta* have been tested for susceptibility to beet yellows (1). Symptoms were produced on all these species and no evidence of a high degree of resistance was found. Some species including *B. macrocarpa* Guss., *B. maritima* L., and *B. patellaris* Moq. were more severely injured than commercial varieties of sugar beet. It seems unlikely that any of the species tested will be of value in a program of breeding for resistance

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[3] Numbers in parentheses refer to literature cited.

to beet yellows. The resistance of wild species of *Beta* to western yellows has not been determined.

Experimental Methods

Replicated field tests were made at Salinas in 1957 and 1958 to determine the relative resistance of our present varieties and breeding stocks to beet yellows. The degree of resistance to yellows was determined by comparing inoculated and noninoculated plots of each variety or breeding stock (Figure 1). Inoculations were made with a virulent strain of the beet-yellows virus by the method described by Bennett, Price, and McFarlane (3) in which leaf pieces containing about 10 green peach aphids, *Myzus persicae* (Sulz.), were removed from source plants and

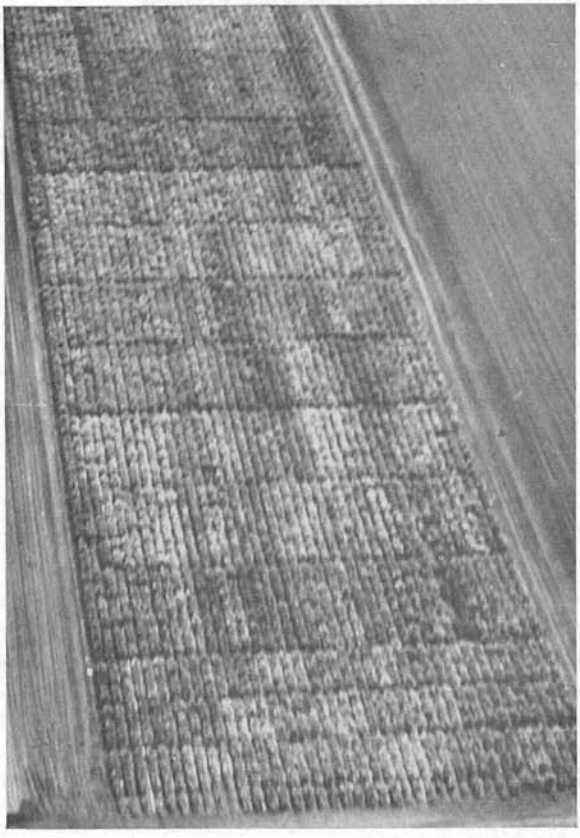

Figure 1.—Aerial view of 1958 beet-yellows resistance evaluation test at Salinas, California. Replications were divided into 2 equal parts 1 of which was inoculated with beet-yellows virus and the other maintained as a noninoculated check. Some natural infection occurred in the noninoculated plots.

placed on the plants being inoculated. Plots were sprayed with an aphicide 24-48 hours after inoculation.

1957 Tests. Plantings were made in December 1956 and in May 1957 to survey the level of resistance in a wide range of varieties and breeding lines. The December planting consisted of bolting-resistant varieties, selections, and inbreds from the United States Department of Agriculture breeding program at Salinas, California. One test included 12 varieties replicated 5 times and a second test consisted of 80 inbreds replicated twice. Each replication of each entry in both tests was divided into 2 adjacent plots, 1 of which was inoculated with yellows virus and the second maintained as a check. The plots were 2 rows wide by 50 feet long in the variety test and 1 row wide by 22 feet long in the inbred test. Spraying to control the aphid vectors was started March 16 and continued at 10- to 14-day intervals through July. The plots were inoculated April 15. The inoculated plots were graded for yellowing and estimates made of percent stunting and necrosis on June 6 and again on June 25. Percent spread of yellows to the noninoculated plots was also determined on these dates. The tests were harvested August 20-23 and data obtained on root yields and sucrose percentage.

The May planting included 256 varieties, selections, and inbreds furnished by sugar beet breeders in the United States and Europe. Each entry was replicated 2 times and divided into inoculated and noninoculated plots as in the December planting. The plots were 1 row wide by 25 feet long. Spraying for aphid control was started as soon as the plants emerged and continued until August 15. Inoculations were made July 1. The plots were graded for yellowing and estimates made of percent stunting and necrosis on August 9 and again on August 21. The test was harvested September 20-25 and root yields obtained.

1958 Tests. Field tests were planted December 13, 1957, and May 1, 1958, to determine the resistance of additional varieties and breeding lines and to recheck the resistance of lines which showed the least damage in the 1957 tests. The damage from yellows was determined as in 1957 except that the inoculated and noninoculated plots were placed end to end rather than side by side. This end-to-end arrangement permitted one half of each replication to be inoculated as a block.

The December planting included separate tests of 8 bolting-resistant varieties and 8 bolting-resistant inbreds. Both the varieties and the inbreds were replicated 4 times. The plots were 2 rows wide by 40 feet long in the variety test and 2 rows wide by 25 feet long in the inbred test. The entire planting was

sprayed with an aphicide at 7- to 10-day intervals beginning March 3 and ending July 15. Inoculations were made March 4 and the plots were harvested August 13-15.

The May planting included separate tests of 14 varieties or selections and 14 inbred lines. Four replications of each entry were used. The plots were 2 rows wide by 40 feet long in the variety test and 2 rows wide by 25 feet long in the inbred test. Spraying to control aphids was started May 20 and continued at 7- to 10-day intervals through August 15. Inoculations were made June 25 and the plots were harvested September 10 and 11.

Selecting for Resistance. Field and greenhouse selections were made for yellows resistance between 1957 and 1961. The greenhouse selections were from plants grown in 6-inch plots and inoculated with beet yellows virus when the plants were 6 weeks old. Selections were based on relative freedom from yellowing and on root size. Major attention was placed on root size and the selections were made when the plants were approximately 4 months old.

The field selections were from plantings arranged in form of a checkerboard so that each plant occupied an area 28 × 28 inches. This arrangement tended to equalize competition between plants and reduced the danger of selecting large beets which had received an unfair competitive advantage. Inoculations were made when the plants were about 7 weeks old. Selections were based on freedom from top symptoms and on root size with major attention on root size.

Field inoculations were made with a virulent strain of beet-yellows virus through 1960. In 1961 a combination of beet and western-yellows viruses was used to inoculate beets grown for selection purposes.

Results

Resistance to Damage from Yellows. Infection ranging between 90 and 100% was obtained in nearly all inoculated plots in both 1957 and 1958. Aphid populations remained high throughout both growing seasons and yellows gradually spread to the noninoculated plots even though the plantings were sprayed with an aphicide at 10- to 14-day intervals. By harvest time nearly all plants in the noninoculated plots were infected with yellows in both years. Spread to the noninoculated plots occurred more rapidly when they were placed alongside the inoculated plots than when the inoculated and noninoculated plots were placed end to end.

Reduction in yield and sucrose percentage for the 12 varieties in the December 1957 planting are shown in Table 1. The re-

Table 1.—Effect of beet yellows on the performance of sugar beet varieties in a December 17, 1956, planting at Salinas, California.

Variety	Noninoculatd plots (Checks)			Reduction by disease in inoculated plots			Infection in checks
	Gross sugar per acre	Beets per acre	Sucrose	Gross sugar	Beets	Sucrose	
	Pounds	Tons	Percent	Percent	Percent	Percentage points	Percent
461HO × US 201B	9,560	30.1	15.88	26.7	24.7	0.62	22.6
US 56/2	9,800	30.4	16.12	30.1	26.6	0.36	24.7
US 15 × US 22/3	10,300	32.3	15.94	32.1	31.1	0.74	23.6
616[a]	11,750	36.8	15.96	33.4	31.7	0.44	17.5
5513HO × 672	10,300	32.0	16.10	33.7	29.3	1.00	25.3
511[b]	10,030	31.1	16.12	34.1	30.5	0.86	19.2
5513HO × NB4	10,190	33.4	15.26	36.5	34.0	0.60	25.3
US H6	11,890	35.9	16.56	37.8	33.7	1.14	14.3
5570-49-11H1 × 6576	11,710	34.1	17.22	38.1	32.8	1.40	16.3
515[c]	10,260	32.9	15.60	40.0	36.1	0.98	19.2
US 75	10,250	31.9	16.06	41.1	37.6	0.90	25.6
MS of NBL × NB4	10,970	34.1	16.08	41.4	36.8	1.18	13.6
L.S.D. (5%)	1,320	NS	0.65	8.0	7.6	NS	7.7

[a] Field selection from US 75 for beet-yellows resistance made by Charles Price.
[b] Greenhouse selection from US 75 for beet-yellows resistance.
[c] Field selection from US 75 for beet-yellows resistance made by Charles Price.

duction in yield of roots ranged from 24.7 to 37.6% and the difference between varieties was significant at the 1% point. The loss in sucrose percentage in the 12 varieties ranged from 0.36 to 1.40 percentage points, but the difference between varieties was not significant. Yield reductions from beet yellows among 80 inbreds included in 2 replications in the December 1957 inbred test ranged from 10.4 to 55.5%.

Yield reductions in the May 7, 1957, planting were greater than those in the December planting. Yields were reduced from 16.6 to 49.4% in 91 varieties and selections included in 2 replications in the May planting. Yields of 165 inbreds were reduced from 9.0 to 65.1% in the same planting. The performances of representative groups of these varieties and inbreds are shown in Table 2.

Table 2.—Effect of beet yellows on root yield of sugar beet varieties and inbreds in a May 7, 1957, planting at Salinas, California.

Varieties	Acre yield[a]		Reduction in yield
	Check	Yellows	
	Tons	Tons	Percent
A7/S1	30.1	25.1	16.6
IRS 55M9	23.3	19.4	16.7
US 400	24.3	18.2	25.1
US 56/2	21.9	15.8	27.9
MS of NB1 × NB2	26.9	18.5	31.2
US H2	29.1	19.8	32.0
MS of NB1 × NB4	29.2	17.7	39.3
Klein E	28.9	14.6	49.4
Inbreds			
F1 287	21.1	19.2	9.0
TASCO 5-148	20.3	17.6	13.3
F1 282	16.5	11.8	28.5
SL 618	15.4	10.0	35.1
NB4	17.7	9.9	44.1
NB1	18.6	9.7	47.8
NB2	19.7	8.5	56.8
5508-113	10.9	3.8	65.1

[a] Acre yield is an average of two replications.

The 1957 tests demonstrated that a wide range of resistance to beet yellows exists within *Beta vulgaris* L., but varieties or breeding lines immune or highly resistant were not found. Percent yield reductions varied greatly among replications emphasizing the necessity for adequate replication in resistance-evaluation tests.

Reductions in yield and sucrose percentage of the 8 varieties in the December 1958 planting are shown in Table 3. Root yields were reduced 24.1 to 44.0%. This difference between

Table 3.—Effect of beet yellows on the performance of sugar beet varieties in a December 13, 1957, planting at Salinas, California.

Variety	Noninoculated plots (checks)			Reduction by disease in inoculated plots			Infection in checks
	Gross sugar per acre	Beets per acre	Sucrose	Gross sugar	Beets	Sucrose	
	Pounds	Tons	Percent	Percent	Percent	Percentage points	Percent
MS of NB6 × NB5	10,100	36.1	14.35	26.5	26.2	0	10.5
MS of 515 × 569	9,360	27.7	16.93	27.3	24.1	0.65	14.3
711[a]	9,960	33.2	14.98	28.2	26.0	0.35	13.5
MS of NB1 × NB4	12,000	42.3	14.15	31.6	28.3	0.62	3.9
US 75	10,440	34.6	15.08	36.8	33.2	0.83	17.3
US H5A	11,320	39.3	14.35	37.0	35.2	0.27	10.5
MS of NB1 × NB2	11,710	39.3	14.85	41.2	38.0	0.50	5.4
US 15 selection	11,770	39.5	14.93	46.0	44.0	0.45	17.2
L.S.D. (5%)	880	4.0	1.33	12.2	12.1	NS	7.5

[a] Second successive field selection from US 75 for beet-yellows resistance.

varieties was significant at the 1% point. Sucrose percentages were reduced in the yellows-inoculated plots, but the reductions varied so much from one plot to another that differences between varieties were not significant. The 1957 and 1958 results indicate that yield data give a more accurate measure of beet-yellows resistance than do sucrose data.

Yield reductions for the 14 varieties and 14 inbreds in the May 1958 planting are shown in Table 4. Losses in the varieties ranged from 11.8 to 36.2% and those in the inbreds ranged from 20.4 to 44.2%. Selections made for beet-yellows resistance at the Institute voor Rationele Suikerproductie, Bergen op Zoom, The Netherlands (IRS numbers), showed the least damage.

Table 4.—Effect of beet yellows on the performance of sugar beet varieties and inbreds in a May 1, 1958, planting at Salinas, California.

Varieties	Acre yield		Reduction in yield	Infection in checks
	Check	Yellows		
	Tons	Tons	Percent	Percent
IRS 55M24	22.0	19.4	11.8	13.0
715-1	12.6	11.0	12.7	2.2
IRS 55M9	21.1	18.2	13.7	13.8
IRS 55M14	20.1	16.9	15.9	10.9
MS of NB1 × NB4	27.9	22.1	20.8	8.6
IRS M1-1953	18.9	14.3	24.3	6.7
MS of NB1 × NB2	24.2	18.1	25.2	5.4
Sel. from US 104	23.5	18.7	26.7	13.7
711	26.4	19.3	26.9	15.9
MS of NB6 × NB5	23.9	17.3	27.6	11.0
Sel. from US 104	20.2	14.4	28.7	13.4
US 75	27.7	19.7	28.9	15.8
US 15 selection	26.8	18.4	31.3	18.2
Sel. from US 201	13.8	8.8	36.2	14.0
L.S.D. (5%)	2.4	1.9	7.4	5.3
Inbreds				
55-RF393	23.0	18.3	20.4	11.4
5614	22.1	17.4	21.3	7.2
SL 7807	19.1	14.8	22.5	5.5
SLC 117	14.6	11.1	24.0	15.8
NB4	17.3	13.1	24.3	4.3
NB1	17.3	13.0	24.9	3.4
5577-2	19.5	14.3	26.7	5.3
SL 6509	16.0	11.6	27.5	9.7
5628-24	19.5	14.1	27.7	20.1
NB5	15.5	11.1	28.4	10.8
NB6	19.3	13.6	29.5	5.4
TASCO 6-278	14.3	9.6	32.9	35.3
TASCO 5-148	21.8	13.8	36.7	23.2
NB2	15.6	8.7	44.2	10.5
L.S.D. (5%)	3.8	2.5	8.2	6.7

Varieties and inbreds selected as possessing resistance to beet yellows in the 1957 tests tended to perform well in 1958. There was also reasonably good agreement among the results for the different planting dates. The IRS 55M9 variety showed superior resistance in both 1957 and 1958. The NB2 inbred and the US 15 selection were severely damaged in each of the tests in which they were included. Where disagreement in results occurred, the test with the greater number of replications is considered the more accurate.

Variation in Susceptibility to Infection. The 1957 and 1958 tests provided an opportunity to determine the relative resistance of the varieties and inbreds to natural infection with yellows. Aphid build-ups in the tests were prevented by spraying regularly with an aphicide. Infection in the noninoculated plots was primarily from wind-borne winged aphids and took place at a relatively slow rate. Counts in the December 1956 planting showed that infection in 12 varieties ranged from 13.6 to 25.6% in the noninoculated checks (Table 1). In the December 1957 planting infection ranged from 3.9 to 17.3 percent (Table 3) and in the May 1958 planting from 2.2 to 35.3 percent (Table 4). Differences between varieties and inbreds were significant at the 5% level.

Counts were also made in an unsprayed variety evaluation test planted in a commercial sugar beet field near Salinas. Only a moderate amount of yellows infection occurred in this field and an accurate determination was made of spread among 12 varieties included in the test. The amount of infection ranged from 15.0 to 34.7% and the difference between varieties was significant at the 1% level.

The results of the 1957 and 1958 tests demonstrate that differences exist among varieties and inbreds in susceptibility to yellows infection. No attempt was made to identify the yellowing virus which caused the natural infection. Western-yellows virus was predominant in the Salinas district in both years and probably much of the natural infection was with this virus.

No relation was found between resistance to infection and resistance to damage from yellows nor was there a clear-cut relation between color of foliage and susceptibility to natural infection with yellows. Inbred lines with dark-green foliage showed a wide range in susceptibility to infection. Inbreds with light-green foliage tended to be susceptible; however, some lines with light-colored foliage showed only moderate infection.

Progress in Selecting for Resistance to Beet Yellows. Some uncertainty exists as to the relative reliability of greenhouse and

field techniques of selecting for beet yellows resistance. Watson and Russell (9) reported that scores for severity of symptoms made in the greenhouse were positively correlated with similar scores made in a field experiment through the use of 2 cultivated and 2 wild beet types. The symptom scores were also positively correlated with losses in root and sugar yields caused by the beet-yellows virus. Observations thus far in California indicate that greater progress can be made by selecting in the field than in the greenhouse. Top symptoms of plants grown and inoculated in the greenhouse tended to be more uniform than those in field plantings. Wide variations in root size occurred in greenhouse-grown plants, but these variations were more closely associated with differences in environment among plants than with differences in resistance.

In the California field program greatest emphasis has been placed on the development of a beet-yellows resistant selection of US 75. Successive selections based primarily on superior root size were compared with the parent variety in 1960 and 1961 replicated tests (Table 5).

Table 5.—Progress in selecting for yellows resistance in US 75 at Salinas, California.

Variety	Acre yield of noninoculated check		Reduction in yield		
			Beet yellows		Beet and west. yel.
	1960	1961	1960	1961	1961
	Tons	Tons	Percent	Percent	Percent
US 75	27.1	19.4	31.7	33.1	42.1
Sel. from US 75	28.3[a]	17.6[b]	25.3	15.8	24.2

[a] Third successive selection for beet-yellows resistance.
[b] Fourth successive selection for beet-yellows resistance.

Both the third and fourth successive selections from US 75 were significantly more resistant to beet yellows than the parent variety. The resistance of the fourth successive selection to the combination of beet and western yellows was also significantly greater than that of US 75. These results indicate that a correlation may exist between resistance to beet and western yellows.

The fourth successive selection and the parent US 75 variety were included in three variety trials in 1961. In each of these trials both the root yield and sucrose percentage were similar in the selection and in US 75.

Correlation between root-yield reduction and top symptoms. Correlation coefficients were computed between reduction in root yield from beet yellows and stunting, yellowing, or necrosis of tops. These coefficients were computed separately for varieties and for inbreds in each of the replications of the 1956-57 tests

Table 6.—Correlation coefficients between yield reduction from beet yellows and the top symptoms stunting, yellowing, and necrosis.

Date of Planting	Type of material	Stunting		Yellowing		Necrosis	
		Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
December 1956	Inbreds	.07	.24*	.48	.19	.12	.09
December 1956	Varieties	−.16	.32	.33	.33	.28	.06
May 1957	Inbreds	.46**	.45**	.26**	.02	.36**	.02
May 1957	Varieties	.59**	.52**	.40**	.04	.51**	.02

* Significant at 5% point.
** Significant at 1% point.

(Table 6). In the December planting very little correlation existed between yield reduction and any of the top symptoms. In the May planting a significant positive correlation was found between yield reduction and stunting in both inbred and variety tests. In one replication, yield reduction was also correlated with yellowing and with necrosis.

None of these correlation coefficients was high. Yield reduction was most closely associated with stunting, but even this association varied greatly from one variety or inbred to another.

The results of these tests show that none of these three top symptoms will serve as a reliable selection criterion. Yellowing and stunting are undesirable characters in a sugar beet variety; so preliminary selections can be made for relative freedom from these characters. Unless a reliable biochemical technique is developed (6), true resistance can be determined only through yield comparisons of yellows-infected and noninfected beets. The necessity of using yield measurements to determine resistance limits the size of populations which can be handled in a breeding program and adds greatly to the cost of developing resistant varieties.

Summary

Tests at Salinas, California, in 1957 and 1958 with more than 350 sugar beet varieties and breeding lines showed that a wide range of resistance to beet yellows exists within *Beta vulgaris* L. Yield losses among lines ranged from 9.0 to 65.1%. Immune or highly resistant lines were not found.

Natural infection with yellows (probably largely western yellows) in noninoculated varieties and breeding lines ranged from 2.2 to 35.3% indicating that differences also exist in resistance to yellows infection. Resistance to infection was not related to resistance to damage from yellows nor was there a clear relation between color of foliage and resistance to natural infection.

The yellows resistance of US 75 was improved by selecting in the field from plants inoculated with a virulent strain of beet-

yellows virus. The root yield of the fourth successive selection from US 75 was reduced 15.8% by beet yellows compared with a reduction of 33.1% in the parent variety.

Correlations between reduction in root yield and stunting, yellowing, or necrosis of tops were low in plants affected by beet yellows. None of these three types of top symptoms will serve as a reliable selection criterion. True resistance can be determined only from yield comparisons of diseased and healthy beets.

Literature Cited

(1) BENNETT, C. W. 1960. Sugar beet yellows disease in the United States. U. S. Dept. Agr. Tech. Bull. 1218.

(2) BENNETT, C. W. and J. S. MCFARLANE. 1959. Effect of the virus yellows on sugar beet seed production. Plant Disease Rptr. 43: 1188-1190.

(3) BENNETT, C. W., CHARLES PRICE, and J. S. MCFARLANE. 1957. Effects of virus yellows on sugar beets with a consideration of some of the factors involved in changes produced by the disease. J. Am. Soc. Sugar Beet Technol. 9: 479-494.

(4) DUFFUS, JAMES E. 1960. Radish yellows, a disease of radish, sugar beet, and other crops. Phytopathology. 50: 389-394.

(5) DUFFUS, JAMES E. 1961. Economic significance of beet western yellows (radish yellows) on sugar beet. Phytopathology. 51: 605-607.

(6) FIFE, J. M. 1961. Changes in the concentration of amino acids in sugar beet plants induced by virus yellows. J. Am. Soc. Sugar Beet Technol. 11: 327-333.

(7) HILLS, ORIN A., C. W. BENNETT, H. K. JEWELL, DONALD L. COUDRIET, and ROSS W. BRUBAKER. 1960. Effect of virus yellows on yield and quality of sugar beet seed. J. Econ. Entomol. 53: 162-164.

(8) RIETBERG, H., and J. A. HIJNER. 1956. Die Bekämpfung der Vergilbungskrankheit der Rüben in den Niederlanden. Zucker 9: 483-485.

(9) WATSON, MARION A. and G. E. RUSSELL. 1956. The value of glasshouse tests with seedlings in selecting plants tolerant to beet yellows virus. Ann. Appl. Biol. 44: 381-389.