# Breeding Sugarbeet for Resistance to Yellow Wilt[1]

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## Introduction

Yellow wilt, potentially an extremely destructive disease of sugarbeet, is reliably considered the principal cause of the collapse of the beet sugar industry in Argentina more than 30 years ago (2, 3, 4).[4] In Chile, the disease was first recognized in experimental sugarbeet plantings in 1945 and has been present in the commercial sugarbeet crop since the beginning of the beet sugar industry in that country about 9 years later (1). That industry currently is coping with the disease by avoiding areas where incidence of the vector (*Paratanus exitiosus* Beamer) is especially high and by the use of certain modern insecticides (1). Effectiveness of the latter is dependent upon accurate entomological surveillance and precise timing of insecticide applications with respect to vector migrations. Consequently, control costs are substantial and effectiveness is variable (8).

Yellow wilt also is an important problem in the production of sugarbeet seed in Chile. Arentsen et al. (1) reported that the severity of the disease resulted in the shifting of the sugarbeet-seed industry southward, first from the province of Coquimbo (north of Santiago) to the province of Aconcagua, during the 1950's, and later to the zone between Santiago and Curicó. The use of insecticides for control of the vector is now a standard practice in all sugarbeet seed fields in Chile.

Although yellow wilt has been found only in Chile and Argentina, it must be considered a very serious threat to the sugarbeet crop in many parts of the world, including much of the western United States. To illustrate this point, it is pertinent to point out the following: (a) The only known vector is a leafhopper that thrives on many weed species common throughout the semiarid regions of the world where the sugarbeet is adapted, including the western United States; (b) most

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[4] Single-digit numbers in parentheses, occurring in the text, refer to literature cited.

of the best host species of the vector also are hosts of the recognized causal agent of yellow wilt; and (c) climatic conditions where the vector thrives in Chile and Argentina are similar to those in many other semiarid regions suitable for sugarbeet production, including much of the western United States (3, 4, 5). Apparently, the vector occurs only in Chile and Argentina at present. However, with modern methods of transportation, its spread to other regions seems inevitable.

The chief purpose of this article is to describe the progress made in breeding sugarbeet for resistance to yellow wilt. However, since important etiological, host-range, and other information has been accumulated since the drafting of the comprehensive 1967 report by Bennett et al. (3), this article has been expanded to include some of the new information. For further details in this category, the reader is referred to "Literature Cited," particularly (1), (4), and (9).

### *Host Range of the Disease*

A list of plant hosts of yellow wilt was included in the article by Bennett et al. (3). A list of host species, expanded to include more recent observations (1, 4, 5), is presented in Table 1. Of the 12 families represented by the 43 species listed, the Chenopodiaceae, Cruciferae, and Geraniaceae probably are the most important as sources of yellow wilt inoculum for the sugarbeet crop in Chile.

### *Host Range of the Vector*

The only known vector of yellow wilt, *Paratanus exitiosus* Beamer, belongs to the same subfamily of insects as the beet leafhopper (*Circulifer tenellus* Baker), the vector of North American sugarbeet curly top, and the wide host range of the two species is about the same (3, 4). The following statement by Bennett (4) is particularly significant: ". . . nearly all of the best host plants for *P. exitiosus* are also hosts of the causal agent of the yellow wilt disease."

### *Causal Agent or Agents of the Disease*

For many years yellow wilt was believed to be caused by a virus (2, 3). Before 1967, no mycoplasma-like organism (MLO) was known to be the causal agent of any plant disease. The possibility that yellow wilt is caused by an MLO was suspected when it was observed that temporary remission of symptoms occurred following treatment of infected sugarbeet plants with certain antibiotics (1, 4, 7). Strong confirming evidence subsequently was obtained by Urbina-Vidal and Hirumi at the Boyce Thompson Institute for Plant Research, Yonkers, N.Y., in 1973 (9). Electron micrographs consistently showed abundant bodies of MLO type in tissue specimens from yellow-wilt-infected sugarbeet plants and no such bodies in specimens from apparently healthy plants. However, the results of this study also suggested the

**Table 1. — Plant hosts of yellow wilt.**

| Family | Species | Remarks |
|---|---|---|
| Aizoaceae | *Tetragonia tetragonioides* (Pall.) Ktze. | New Zealand Spinach |
| Amaranthaceae | *Amaranthus retroflexus* L.*# | Red-root amaranth; pigweed |
| Caryophyllaceae | *Stellaria media* (L.) Cyrillo*# | Chickweed; common in shady places |
| Chenopodiaceae | *Beta macrocarpa* Guss. | |
| | *Beta maritima* L. | |
| | *Beta patellaris* Moq. | |
| | *Beta vulgaris* L. | Sugarbeet, table beet, fodder beet |
| | *Beta vulgaris* L. var. *cicla* L. | Swiss chard |
| | *Chenopodium album* L.*# | Lambsquarters |
| | *Chenopodium capitatum* (L.) Aschers.# | Strawberry blite |
| | *Chenopodium murale* L.*# | Nettle-leaf goosefoot |
| | *Spinacia oleracea* L. | Spinach. Highly susceptible to yellow wilt and may show symptoms in 9 days after infection. An excellent host of |
| Compositae | *Cichorium intybus* L.*# | |
| | *Picris echioides* L.*# | Ox-tongue. Shows marked symptoms when infected, but diseased plants may have symptomless shoots. |
| | *Sonchus* sp.* | |
| | *Taraxacum officinale* Web.*# | |
| Convolvulaceae | *Convolvulus arvensis* L.*# | Bindweed. Shows marked symptoms of yellow wilt when infected, but apparently is very resistant to infection. |
| Cruciferae | *Brassica* sp.*# | |
| | *Capsella bursa-pastoris* (L.) Medic.*# | Shepherd's purse |
| | *Diplotaxis muralis* (L.) DC.*# | A very good host of *P. exitiosus* |
| | *Lepidium bipinnatifidium* Desv.* | Highly susceptible to infection and injury |
| | *Rapistrum rugosum* (L.) All.* | Yuyo |
| | *Sisymbrium officinale* (L.) Scop.*# | Hedge mustard |
| Geraniaceae | *Erodium botrys* (Cav.) Bertol.*# | An excellent host of *P. exitiosus* |
| | *Erodium cicutarium* (L.) L'Her.*# | Red-stem filaree. An excellent host of *P. exitiosus* |
| | *Erodium moschatum* (L.) L'Her.*# | White-stem filaree. An excellent host of *P. exitiosus* |

* = Common weed in Chile
\# = Common weed in the United States

| Family | Species | Remarks |
|---|---|---|
| Plantaginaceae | *Plantago insularis* Eastw.# | |
| | *Plantago lanceolata* L.*# | |
| | *Plantago major* L.*# | Common plantain. Excellent host of *P. exitiosus* |
| | *Plantago virginica* L.*# | |
| Polygonaceae | *Polygonum lapathifolium* L.*# | |
| | Rumex crispus L.*# | Dock |
| | *Rumex* spp. | Dock; at least two species |
| Portulacaceae | *Calandrinia compressa* Schrad. ex DC.* | |
| | *Claytonia perfoliata* Donn. ex Willd.# | Miner's lettuce |
| | *Portulaca oleracea* L.*# | Purslane |
| Solanaceae | *Datura stramonium* L.*# | Jimson weed |
| | *Hyoscyamus niger* L. | Black henbane |
| | *Lycopersicon esculentum* Mill. | Tomato. Apparently not highly susceptible to infection, but severely injured if infected. |
| | *Nicotiana bigelovii* (Torr.) S. Wats.# | Indian tobacco |
| | *Nicotiana clevelandii* Gray | |
| | *Nicotiana quadrivalvus* Pursh | |

* = Common weed in Chile
\# = Common weed in the United States

possibility that in addition to MLO, a virus is involved in the yellow wilt disease. It is conceivable that the presumptive virus, observed in yellow-wilt-infected material, plays a complementary role, a negative role, or no role at all, in the expression of symptoms. Further elucidation of this matter is urgently needed.

## Breeding for Resistance

### *Materials, Methods, and Background Information*

More than 381 sugarbeet breeding lines and varieties were evaluated under yellow wilt conditions in Argentina (1938-40) and Chile (1965-69), but none exhibited appreciable resistance (4). Other forms of *Beta vulgaris* L. (e.g., Swiss chard, table beet, and fodder beet) were found to be quite susceptible, as were *B. macrocarpa* Guss. and *B. patellaris* Moq. (3, 4).

In the early selection and breeding work in Argentina and Chile, sugarbeet plants without symptoms of the disease were selected under severe yellow wilt conditions. The progenies were about as susceptible as the parental varieties, and it was concluded that the selected plants were merely escapees (2, 3, 4).

Subsequently, in Chile, emphasis was placed on the selection of plants with symptoms of the disease but with some evidence of resistance — i.e., apparent ability to grow in spite of infection. When selected plants with definite yellow wilt symptoms in the fall were removed from the field at that time, given appropriate artificial thermal induction, and transplanted in the spring, all died without producing seed (4). The outcome was the same when such selected plants were transplanted in the fall and allowed to remain in the field throughout the winter and spring (4). When such plants, chosen in the fall, were allowed to remain in the field without transplanting, nearly all died without producing seed. In some large groups of such material, rare individuals produced very small amounts of seed (4).

Although the selection of infected but apparently resistant plants has been emphasized in Chile since the early selection work referred to above, other methods have not been excluded. In fact, one of the most promising categories of material, RS-2b, is a product of reproduction by 5 female plants, none of which developed symptoms during the season of vegetative growth or during the following winter and early spring.

It has been long recognized that some important conventional techniques apparently could not be used in breeding sugarbeet for yellow wilt resistance without a means of obtaining reasonably satisfactory seed production by selected (infected) plants after transplanting. Based on earlier evidence that certain antibiotics can temporarily suppress symptoms (1, 4, 7), attempts were made in 1972 and 1973 to promote the production of seed by selected (infected) plants by means of repeated antibiotic applications throughout the winter and spring (8). The results in 1972 were inconclusive with respect to transplanted plants but were quite encouraging where treated plants were left undisturbed in the field evaluation and selection plots at the Estación Experimental La Platina, near Santiago, Chile. In 1973, antibiotic treatments were limited to plants that were transferred from La Platina to isolated locations for seed production. These groups included both infected and apparently noninfected plants. With refinements in techniques and with the aid of favorable weather, the results were relatively satisfactory. The procedure used may be outlined as follows:

1. The selection and digging of plants in the 1972-73 field plots at La Platina were postponed until September, 1973 (i.e., about the end of the winter season).
2. Promptly after selected plants were dug, the foliage was removed and the roots were immersed for 24 hours in a solution of Terramycin in tap water (250 ppm) and then transplanted

in isolated groups in the Noviciado area, about 37 miles northwest of Santiago.

3. Terramycin solution (same as above) was sprayed on the foliage twice each week for about 2 months.

Various sugarbeet cultivars from the United States and Europe have been used as source material for yellow-wilt-resistance selection and breeding. Since curly top exists in Argentina and thus is considered an important potential threat to the Chilean beet sugar industry, curly-top-resistant cultivars from the United States have been used more extensively than others as source material. After several years of selection, reproduction, and preliminary evaluation work, Arentsen et al. (1) and Bennett (5) described the following lines which had shown some evidence of resistance: RS-1, RS-1a, and RS-1b, derived from the USDA line, C663, or US 75; RS-2, derived from US 75; and RS-3, derived from C663. The sources pertain to the initial female parents. The pollen source in each case is unknown.

The derivation of a particularly promising category of material may be described as follows.[5] Plots planted at La Platina on October 15, 1969, included populations of the respective immediate parents of RS-1a, RS-1b, RS-2, and RS-3. After all bolters and other undesirable plants were removed from those lines, 442 individuals remained in the field on June 20, 1970, to overwinter and to produce seed if possible. Of these, 369 showed yellow wilt symptoms and 73 appeared healthy at that time. None of the former produced seed. Most of the remainder developed yellow wilt symptoms during the winter or spring and died prematurely. Actually, only five produced seed. Those five were in the population designated as the immediate parent of RS-1b. Yellow wilt symptoms appeared in four of them by about December 4, 1970, and the fifth plant apparently remained healthy. The seed was harvested on January 2, 1971. That portion obtained from the apparently healthy plant was designated RS-2b(A), that obtained from the four diseased plants was labeled RS-2b(B), and a pool of a part of each of those lots was designated RS-2b. Increases of RS-2b(A) and RS-2b(B) were made promptly at Linares by the field overwintering method. RS-2b was included in the 1971-72 field plots at La Platina, together with RS-1a, RS-1b, RS-2, and RS-3, for evaluation and further selection.

The evaluation and selection programs at La Platina, reported herein, were conducted under conditions of natural disease exposure. The use of an individual-plant rating system, representing severity of yellow wilt attack, was initiated in the 1971-72 experiments. The use of replicated field plots with statistical analyses of the results was begun in 1973-74.

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[5] Records of Roberto Ehrenfeld K.

*Evaluation Tests*

The results obtained in the experiments of 1970-71, as reported by Bennett (5), suggested that some progress had been made in breeding for resistance. The results of 1971-72 and 1972-73 strengthened that tentative conclusion. The outcome of the 1973-74 experiments apparently left no doubt that measurable progress had been made and also indicated that further progress should be possible. A detailed presentation of results of all of these experiments in this report would not be worthwhile. Instead, detailed results are presented for relevant parts of the 1972-73 program and for all but minor portions of the 1973-74 group of experiments.

***Experiments of 1972-73.*** The field experiments at La Platina in the 1972-73 crop season included a date-of-planting study. The summarized results (Table 2) indicated that the severity of yellow wilt attack was consistently and substantially lower in RS-2b(B) than in the commercial check variety, KWS-E. RS-2b(A) was intermediate in severity of attack. Since yellowing and necrosis caused by yellow wilt cannot be shown satisfactorily in black and white photographs, comparisons of KWS-E and RS-2b(B) were presented in color in reports covering the

**Table 2. — Comparison of three sugarbeet lines in a date-of-planting study, La Platina, 1972-73.**

| | Bolters | Plants rated for severity of yellow wilt reaction[3] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | rogued | Total | Disease grade and % total no.[4] | | | | | | Disease |
| Line[1] | (%)[2] | no. | 0 | 1 | 2 | 3 | 4 | 5 | index[4] |
| *Planted Oct. 10, 1972; disease ratings made Aug. 20, 1973* | | | | | | | | | |
| RS-2b(A) | 85.9 | 125 | 17.6 | 6.4 | 13.6 | 26.4 | 22.4 | 13.6 | 2.70 |
| KWS-E | 0.0 | 326 | 17.5 | 11.3 | 8.0 | 12.3 | 42.6 | 8.3 | 2.76 |
| RS-2b(B) | 38.9 | 231 | 53.7 | 8.2 | 6.1 | 7.8 | 18.2 | 6.1 | 1.47 |
| *Planted Nov. 15, 1972; disease ratings made Aug. 21, 1973* | | | | | | | | | |
| RS-2b(A) | 84.4 | 188 | 20.7 | 10.6 | 15.4 | 25.0 | 22.3 | 5.9 | 2.35 |
| KWS-E | 0.0 | 387 | 9.8 | 6.5 | 3.9 | 20.4 | 55.0 | 4.4 | 3.18 |
| RS-2b(B) | 36.7 | 277 | 37.5 | 12.6 | 9.7 | 15.2 | 22.7 | 2.2 | 1.79 |
| *Planted Dec. 18, 1972; disease ratings made Aug. 22, 1973* | | | | | | | | | |
| RS-2b(A) | 52.7 | 512 | 44.5 | 13.7 | 10.7 | 13.7 | 16.8 | 0.6 | 1.46 |
| KWS-E | 0.0 | 404 | 25.5 | 10.6 | 4.5 | 13.9 | 44.6 | 1.0 | 2.44 |
| RS-2b(B) | 17.8 | 376 | 61.4 | 14.1 | 4.0 | 5.9 | 14.6 | 0.0 | 0.98 |
| *Averages* | | | | | | | | | |
| RS-2b(A) | | | 27.6 | 10.2 | 13.2 | 21.7 | 20.5 | 6.7 | 2.17 |
| KWS-E | | | 17.6 | 9.5 | 5.5 | 15.5 | 47.4 | 4.6 | 2.79 |
| RS-2b(B) | | | 50.9 | 11.6 | 6.6 | 9.6 | 18.5 | 2.8 | 1.41 |

[1] Each line occurred in one plot (21 rows × 8.5 m) in each planting-date block. The 9 plots in this experiment were arranged, from east to west, in the order shown.

[2] At convenient intervals during the period, Dec. 13, 1972, to July 20, 1973, inclusive, all bolters were rogued throughout the entire experiment.

[3] All plants remaining in representative rows of each plot after roguing of bolters.

[4] Basis of grades: 0 = without yellow wilt symptoms; 5 = dead. The disease index is a weighted average based on the number of plants in each grade.

1972-73 experiments (8). As these photographs show, the degrees of both yellowing and leaf necrosis, especially the latter, were distinctly lower in RS-2b(B) than in KWS-E. These observations agreed with the numerical comparisons of the same lines (Table 2), although nearly 4 months elapsed from the time the photographs were made to the time the data were recorded.

Another highlight of the 1972-73 results at La Platina was the performance of one of the three introductions of *B. maritima* L. in a separate experiment. That particular introduction had been collected in its wild state several years earlier, near Wembury Bay, England, by Mr. Dewey Stewart, formerly Leader, Sugarbeet Investigations, in the Agricultural Research Service, USDA, now a Collaborator. Disease indexes for three consecutive plots in the experiment were as follows on August 27, 1973: KWS-E, 2.96; table beet, 2.72; and *B. maritima* (Wembury Bay) 1.06. The appearance of the latter is compared with that of the table beet, 4 months earlier, in Figure 2. These results suggest that superior genes for yellow wilt resistance exist in the Wembury Bay introduction of *B. maritima* and in other biotypes of that species.

**Figure 1. — Yellow wilt injury in sugarbeet, typical of that occurring in commercial sugarbeet varieties in Chile in areas where incidence of the vector is high. The picture shows the variety, KWS-E, at La Platina, near Santiago, on April 14, 1972. (BSDF photo 72-J-19).**

**Figure 2. — Comparison of table beet (row at right) with *B. maritima* from Wembury Bay, England; La Platina, April 27, 1973; planted October 10, 1972. (BSDF photo BW73-1-9).**

***Experiments of 1973-74.*** The field experiments at La Platina in the 1973-74 crop season consisted principally of evaluation tests of individual-plant progenies resulting from reproduction of selected plants of several RS lines under conditions of open pollination in 1972 — seed harvested in January, 1973. The 1973-74 plots were planted on November 22, 1973, and thinned and cared for in the usual manner. Bolters were rogued at convenient intervals during the 1973-74 crop season and the following winter. The numbers of such plants were not systematically recorded, and they have been disregarded in this report. As in the preceding year, yellow wilt developed later than usual; consequently, the recording of results was postponed until winter (actually July and August), 1974. This undertaking involved the rating of 17,715 plants individually for severity of yellow wilt attack.

One experiment (no. 4), a test of a few very small seed lots in 2-row plots with two replications, was considered unreliable and the results are not reported herein. Experiment no. 5, with plots 4 rows × 5m in size and with two replications, included six KWS lines or varieties with C663 and RS-2b(B) as checks. The average disease indexes for C663 and RS-2b(B) were 2.78 and 1.99, respectively. The averages for the six respective KWS entries ranged from 2.68 to 2.97. The differences among the seven entries having no background of selection for yellow wilt resistance (i.e. C663 and the KWS material) were considered negligible.

All plots in experiments 1, 2, and 3 were 4 rows × 5m. The material evaluated in those experiments is listed in Tables 3, 4, and 5, respectively, together with the summarized results and the outcome of analyses of variance. The seed numbers for individual-plant progenies, listed in those tables, may be described as follows. Each number consists of four positions, separated by dashes, which indicate, from left to right: (a) the calendar years in which the parental seed was planted and its progeny harvested, respectively; (b) the location or area where

**Table 3. — Comparison of sugarbeet lines for yellow wilt resistance; experiment no. 1, La Platina, 1973-74; 4 replications; results recorded July 16-19, 1974.**

| | | | No. of plants per plot | | Disease index | |
|---|---|---|---|---|---|---|
| **Entry no.** | **Seed no. or variety** | **Description** | **Actual** | **% of RS-2b(B)** | **Actual[1]** | **% of RS-2b(B)** |
| 1 | 71/3-1-3-L15 | 0 | 77.0 | 87 | 1.75** | 131 |
| 2 | -L20 | 0-E | 101.3 | 114 | 1.58** | 118 |
| 3 | 71/3-1-6-L31 | 0-E | 98.8 | 111 | 1.96* | 146 |
| 4 | -L16 | 0 | 59.3 | 67 | 1.28** | 96 |
| 5 | -L17 | 0 | 72.0 | 81 | 1.36** | 101 |
| 6 | -L13 | 0-E | 52.3 | 59 | 1.99* | 149 |
| 7 | 71/3-1-5-L3 | 1 | 104.8 | 118 | 1.46** | 109 |
| 8 | 71/3-1-1-L3 | 0 | 76.0 | 85 | 1.53** | 114 |
| 9 | 71/3-1-5-L4 | 0-E | 101.5 | 114 | 1.47** | 110 |
| 10 | 71/3-1-3-L9 | 1 | 77.8 | 87 | 1.15** | 86 |
| 11 | -L27 | 0 | 72.3 | 81 | 1.79** | 134 |
| 12 | -L14 | 0 | 92.8 | 104 | 1.44** | 107 |
| 13 | -L10 | 1 | 96.8 | 109 | 1.07** | 80 |
| 14 | 71/3-42-3-L2 | 0 | 80.3 | 90 | 1.57** | 117 |
| 15 | 71/3-1-3-L24 | 0 | 92.3 | 104 | 1.18** | 88 |
| 16 | -L25 | 0 | 65.0 | 73 | 1.68** | 125 |
| 17 | 71/3-1-6-L15 | 0-E | 66.3 | 74 | 1.55** | 116 |
| 18 | 71/3-1-1-L6 | 0-E | 93.0 | 104 | 1.76** | 131 |
| 19 | KWS-E | Comm. ck. | 115.8 | 130 | 2.44 | 182 |
| 20 | RS-2b(B) | Yel. wilt res. ck. | 89.0 | 100 | 1.34** | 100 |
| General mean | | | 84.2 | 95 | 1.57 | 117 |
| F | | | | | 5.43## | |
| LSD (.05) for comparison of 4-plot averages | | | | | 0.40 | (30) |
| LSD (.01) for comparison of 4-plot averages | | | | | 0.53 | (40) |

[1] Average severity of yellow wilt reaction, based on individual-plant ratings, using the scale: 0 = absence of yellow wilt symptoms and 5 = dead.

*Disease index significantly below that of KWS-E, on the basis of LSD (.05).

**Disease index significantly below that of KWS-E, on the basis of LSD (.01).

##F greater than the 1% point.

**Table 4. — Comparison of sugarbeet lines for yellow wilt resistance; experiment no. 2, La Platina, 1973-74; 3 replications; results recorded Aug. 6-8, 1974.**

| | | | No. of plants per plot | | Disease index | |
|---|---|---|---|---|---|---|
| **Entry no.** | **Seed no. or variety** | **Description** | **Actual** | **% of RS-2b(B)** | **Actual[1]** | **% of RS-2b(B)** |
| 21 | 71/3-1-6-L28 | 0-E | 112.7 | 115 | 1.88** | 104 |
| 22 | 71/3-1-3-L29 | 0-E | 85.3 | 87 | 2.11** | 117 |
| 23 | -L18 | 0 | 94.3 | 97 | 1.57** | 87 |
| 24 | -L13 | 1 | 120.7 | 124 | 1.53** | 85 |
| 25 | 71/3-1-1-L5 | 0-E | 80.0 | 82 | 1.82** | 101 |
| 26 | 71/3-1-5-L5 | 1 | 112.7 | 115 | 1.82** | 101 |
| 27 | 71/3-1-6-L20 | 0-E | 87.7 | 90 | 2.10** | 116 |
| 28 | 71/3-42-3-L5 | 0 | 80.7 | 83 | 1.73** | 96 |
| 29 | 71/3-1-3-L26 | 0-E | 89.0 | 91 | 1.79** | 99 |
| 30 | -L21 | 0-E | 93.0 | 95 | 1.35** | 75 |
| 31 | 71/3-1-6-L24 | 0-E | 84.3 | 86 | 2.20* | 122 |
| 32 | 71/3-1-1-L4 | 0-E | 92.3 | 94 | 2.46 | 136 |
| 33 | 71/3-1-3-L28 | 0-E | 40.0 | 41 | 1.77** | 98 |
| 34 | 71/3-1-6-L11 | 1 | 75.0 | 77 | 2.45 | 135 |
| 35 | 71/3-1-3-L30 | 0-E | 74.3 | 76 | 1.47** | 81 |
| 36 | 71/3-1-6-L26 | 0-E | 88.3 | 90 | 2.11** | 117 |
| 37 | 71/3-1-3-L4 | 1 | 111.0 | 114 | 1.71** | 94 |
| 38 | 71/3-1-6-L25 | 0 | 89.7 | 92 | 2.16* | 119 |
| 39 | KWS-E | Comm. ck. | 123.7 | 127 | 3.01 | 166 |
| 40 | RS-2b(B) | Yel. wilt res. ck. | 97.7 | 100 | 1.81** | 100 |
| General mean | | | 91.6 | 94 | 1.94 | 107 |
| F | | | | | 2.95## | |
| LSD (.05) for comparison of 3-plot averages | | | | | 0.66 | (36) |
| LSD (.01) for comparison of 3-plot averages | | | | | 0.88 | (49) |

[1] Average severity of yellow wilt reaction, based on individual-plant ratings, using the scale: 0 = absence of yellow wilt symptoms and 5 = dead.

*Disease index significantly below that of KWS-E, on the basis of LSD (.05).

**Disease index significantly below that of KWS-E, on the basis of LSD (.01).

##F greater than the 1% point.

flowering and seed maturation occurred and within which natural transfer of pollen could have occurred by means of wind, insects, etc.; (c) a code number indicating the sugarbeet line serving as the immediate female parent of the new seed lot; and (d) the letter L (libre), indicating open pollination, followed by the female plant number. In the second position, 1 denotes the entire group of 1971-72 evaluation and selection plots at La Platina in which selected plants were allowed to remain for seed production. The number, 42, pertains to a single isolated group at Linares. Third-position numbers denote the following Chilean lines described elsewhere in this report: 1 = RS-1a, 2 = RS-1b, 3 = RS-2b, 5 = RS-2, and 6 = RS-3.

In the description column of each table: 1 indicates that the female plant had developed yellow wilt symptoms by about the end of the vege-

**Table 5. — Comparison of sugarbeet lines for yellow wilt resistance; experiment no. 3, La Platina, 1973-74; 2 replications; results recorded Aug. 12-13, 1974.**

| | | | No. of plants per plot | | Disease index | |
|---|---|---|---|---|---|---|
| Entry no. | Seed no. or variety | Description | Actual | % of RS-2b(B) | Actual[1] | % of RS-2b(B) |
| 41 | 71/3-1-6-L23 | 0-E | 65.0 | 70 | 2.68 | 140 |
| 42 | 71/3-1-3-L22 | 0-E | 93.5 | 101 | 1.53* | 80 |
| 43 | 71/3-1-2-L4 | 1 | 31.5 | 34 | 2.38 | 124 |
| 44 | 71/3-1-6-L29 | 0-E | 88.5 | 95 | 1.76* | 92 |
| 45 | 71/3-1-3-L16 | 0-E | 82.5 | 89 | 1.84 | 96 |
| 46 | 71/3-1-6-L10 | 1 | 60.5 | 65 | 2.36 | 123 |
| 47 | 71/3-1-3-L17 | 0-E | 96.0 | 103 | 1.82* | 95 |
| 48 | 73W601 | RS-2c (Ft. Col. inc.) | 101.0 | 109 | 2.68 | 140 |
| 49 | 73W602 | RS-1 orig. (Ft. Col. inc.) | 83.0 | 89 | 2.51 | 131 |
| 50 | 71/3-42-3-L4 | 0 | 90.0 | 97 | 2.11 | 110 |
| 51 | 71/3-1-5-L1 | 1 | 80.5 | 87 | 2.00 | 104 |
| 52 | 71/3-1-3-L12 | 1 | 59.0 | 63 | 2.56 | 133 |
| 53 | 71/3-1-6-L14 | 0-E | 18.5 | 20 | 2.88 | 150 |
| 54 | 71/3-42-3-L1 | 0-E | 105.5 | 113 | 1.44** | 75 |
| 55 | 71/3-1-6-L22 | 0-E | 83.0 | 89 | 2.05 | 107 |
| 56 | 71/3-1-3-L23 | 0-E | 80.0 | 86 | 1.36** | 71 |
| 57 | -L19 | 1 | 89.5 | 96 | 1.95 | 102 |
| 58 | 71/3-1-6-L27 | 0-E | 70.0 | 75 | 2.73 | 142 |
| 59 | KWS-E | Comm. ck. | 118.5 | 127 | 2.77 | 144 |
| 60 | RS-2b(B) | Yel. wilt res. ck. | 93.0 | 100 | 1.92 | 100 |
| General mean | | | 79.5 | 85 | 2.16 | 113 |
| F | | | | | 2.21# | |
| LSD (.05) for comparison of 2-plot averages | | | | | 0.94 | (49) |
| LSD (.01) for comparison of 2-plot averages | | | | | 1.28 | (67) |

[1] Average severity of yellow wilt reaction, based on individual-plant ratings, using the scale: 0 = absence of yellow wilt symptoms and 5 = dead.

*Disease index significantly below that of KWS-E, on the basis of LSD (.05).

**Disease index significantly below that of KWS-E, on the basis of LSD (.01).

#F greater than the 5% point.

tative growth period (i.e. late in the fall or early in the winter) but appeared to be relatively resistant; 0-E means that the female plant appeared to be without yellow wilt symptoms up to about the end of the vegetative growth period but developed symptoms of the disease later on; and 0 pertains to plants which apparently remained free of the disease.

As was to be expected, the degree of precision, as indicated by F and LSD values, was highest in experiment 1 (4 replications), intermediate in experiment 2 (3 replications), and lowest in experiment 3 (2 replications). Nevertheless, meaningful results were obtained in all three experiments.

Since RS-2b(B) and KWS-E were included as checks in all three experiments and since RS-2b(B) had shown clear evidence of resistance previously, a comparison of those two cultivars is of special interest. As shown in Tables 3, 4, and 5, the disease index for RS-2b(B) was lower than that for KWS-E in each of the three experiments represented. In each of the experiments, 1 and 2, the difference was highly significant, being considerably greater than the value, LSD (.01). In experiment 3, with only two replications, the difference was not significant but closely approached the level of significance represented by LSD (.05). A detailed comparison of RS-2b(B) and KWS-E, with disease-grade frequency distributions, is presented in Table 6. Visual comparisons of the two lines in May, 1974 (Figure 3), were in keeping with the tabulated results in showing distinctly lower severity of yellow wilt attack in RS-2b(B).

**Table 6. — Comparison of two sugarbeet lines in reaction to yellow wilt, showing disease-grade frequency distributions; La Platina, 1973-74.**

| Line | Exp. no. | No. of repl. | Disease grade and average percent of rated population[1] 0 | 1 | 2 | 3 | 4 | 5 | Disease index |
|---|---|---|---|---|---|---|---|---|---|
| KWS-E | 1 | 4 | 19.2 | 11.2 | 9.3 | 27.6 | 32.5 | 0.3 | 2.44 |
| | 2 | 3 | 12.3 | 4.8 | 7.2 | 22.7 | 51.9 | 1.1 | 3.01 |
| | 3 | 2 | 13.0 | 8.8 | 7.7 | 30.5 | 38.8 | 1.3 | 2.77 |
| | Average | | 14.8 | 8.3 | 8.1 | 26.9 | 41.1 | 0.9 | 2.74 |
| RS-2b(B) | 1 | 4 | 50.8 | 11.2 | 6.2 | 17.3 | 14.6 | 0.0 | 1.34 |
| | 2 | 3 | 37.9 | 13.4 | 6.3 | 15.3 | 26.5 | 0.6 | 1.81 |
| | 3 | 2 | 34.8 | 10.2 | 8.0 | 24.5 | 21.0 | 1.6 | 1.92 |
| | Average | | 41.2 | 11.6 | 6.8 | 19.0 | 20.7 | 0.7 | 1.69 |

[1] Basis of grades: 0 = absence of yellow wilt symptoms; 5 = dead.

With reference to the 52 individual-plant progenies in experiments 1, 2, and 3 (Tables 3, 4, and 5), two points are of special interest. First, the disease index for each of 32 of them was very significantly lower (i.e. better) than that of KWS-E with a difference greater than LSD (.01). Second, although none of the individual-plant progenies were significantly lower than RS-2b(B) in disease index, the range of those progenies, particularly those derived from source 3 (RS-2b), strongly indicated that lines superior to RS-2b(B) in resistance can be developed. A comparison between one of the progenies and KWS-E, during the seed ripening period, is shown in Figure 4.

RS-2b(B) and the individual-plant progenies, as a class, were lower than KWS-E in stand (expressed as number of plants per plot, living or dead) at the time the disease ratings were made. This difference was due in part to low germination and/or inadequate seed supplies in some instances. Other, probably more influential factors were the

**Figure 3. — Comparisons of two sugarbeet lines in adjoining 4-row plots, La Platina, May, 1974. Top: KWS-E (left) and RS-2b(B) (BSDF photo BW74-1-11, May 6). Bottom: The same plots, viewed from the opposite end (KWS-E at right) (BSDF photo 74-G-38, May 10).**

**Figure 4. — Comparison of 4-row plots of KWS-E (left) and an individual-plant progeny (entry 13) in 1973-74 experiment no. 1, La Platina, December, 1974. Plants that produced seed in entry 13 included those in which yellow wilt symptoms appeared by the end of the preceding winter as well as those in which the symptoms appeared later, if at all. Note devastation by yellow wilt in KWS-E. (Photo by Roberto Ehrenfeld K.)**

annual tendency and the roguing of bolters in RS-2b(B) and many of the individual-plant progenies. An obvious net result of these factors was more space per plant for such material. A logical question may be whether the space advantage tended to result in a healthier appearance of plants and thus in lower disease-grade ratings than the same plants would have been given under full-stand conditions.

In order to study this question, the correlation coefficient (r) was computed for each of two sets of data. A total of 22 individual-plant progenies, evaluated in experiments 1, 2, and 3, had been obtained from the female parental source 3 (RS-2b) in the group of 1971-72 experimental plots at La Platina. Since more than one experiment was involved, both the stand and the disease index values were used as percent of RS-2b(B). On this basis, stand for the 22 progenies ranged from 41 to 124 (average 91.9) and disease indexes ranged from 71 to 134 (average 99.2). The r value computed from those data (−0.3152) was not significant according to the "t" test.

The same procedure was used for the 17 individual-plant progenies that had been obtained from the female parental source 6 (RS-3) in the group of 1971-72 experimental plots at La Platina. In this instance, stand ranged from 20 to 115 (average 79.8) and disease index from 92 to 150 (average 122.1). The r value (−0.4377) was not significant.

If there had been a tendency for poor stands to result in low disease indexes, then positive correlation coefficients would have been expected from the above computations. Since the correlation coefficients actually were negative in both instances, it appears that no such relationship existed in the experiments involved. On the contrary, these results suggest the possibility that poor stands tended to result in some elevation of disease indexes. However, it should be emphasized that neither of the r values was significant and that definite conclusions regarding this point must await further study.

### *Discussion*

The question could be raised as to whether the superior performance of RS-2b(B) and other breeding lines under natural yellow wilt exposure at La Platina, as shown in Tables 2, 3, 4, 5, and 6, could have been a result of insect preferences. Preliminary research on this subject was planned in 1972 but, for reasons of practicality, the work had to be postponed. However, a report of certain observations is pertinent. The differences in disease index, between RS-2b(B) and the commercial check variety, KWS-E, were about the same in the large plots of 1972-73 (Table 2) and the small plots of 1973-74. As pointed out elsewhere in this report, selected (infected) plants, left in place in the field, generally produced very little or no seed in earlier breeding work in Chile. A change in this pattern was observed in the late spring and summer of 1973-74 (i.e., November through January) when numerous selected (infected) plants of RS-2b(B), left in place in the 1972-73 evaluation plots at La Platina, produced vigorous seed stalks and relatively satisfactory quantities of seed without the aid of antibiotics. A similar outcome was experienced a year later from such plants of RS-2b(B) and of the best individual-plant progenies listed in Tables 3, 4, and 5, cared for in the same way. Comparable plants of KWS-E produced essentially negligible growth during this reproductive period (Figure 4). These comparisons of reproductive development strongly indicated that post-infection resistance to yellow wilt is substantially higher in the best current breeding lines than in any breeding lines existing several years ago.

As indicated previously in this report, early experience in Argentina and Chile led to the conclusion that, although yellow wilt conditions were severe in the selection fields, plants without symptoms of the disease at the end of the growing season were of little if any value in breeding for resistance. Consequently, emphasis subsequently was placed on the selection of plants with symptoms but with apparent ability to grow in spite of infection. In view of recent developments including, especially, the results presented in this report, it now appears that reevaluation of the earlier conclusion is in order.

The results from the 1973-74 experiments showed that one of the principal factors contributing to the superior performance of numerous lines was a relatively high percentage of plants classed as grade 0 (i.e. without yellow wilt symptoms), in contrast with the percentage of such plants in highly susceptible material. Such contrasts, with respect to KWS-E and RS-2b(B), are summarized for three experiments in Table 6. Similar contrasts, recorded in the date-of-planting study in the preceding year, may be seen in Table 2. Furthermore, it should be recalled that RS-2b(B), apparently the most resistant of the breeding lines tested repeatedly to date, is a product of several female plants, none of which showed symptoms of yellow wilt until late in the spring of the reproductive development period. In other words, those plants remained without symptoms throughout the season of vegetative growth (spring, summer, and fall), throughout the following winter, and throughout most of the following spring (see the section, "Materials, Methods, and Background Information," for further details). In view of these observations, it seems logical to conclude that, in some of the current breeding material, at least, plants without yellow wilt symptoms at the end of the regular growing season, or at the end of the following winter, may be valuable for resistance-breeding purposes. Consequently, in our opinion, such plants should be included in the breeding program, in the foreseeable future, in addition to plants showing mild symptoms.

A strong annual tendency has been observed in many of the lines developed in the breeding program (e.g., see Table 2). This trend is not clearly understood. Bennett (4) has mentioned that the winter season at La Platina is too mild in some years to give adequate thermal induction to plants overwintering in the field. Thus, in such years, bolting-resistant genotypes tend to be eliminated from the breeding program. Another factor that undoubtedly contributed toward annualism in certain instances was the harvesting and subsequent use of seed from annual plants — i.e., plants that bolted in the field plots during the regular growing season.

The presence of plants with varying degrees of Swiss chard characteristics in breeding lines described in this report indicated that contamination by chard had occurred earlier in the development of those lines. The sources and mechanisms of such contamination are not known. However, Swiss chard apparently escaped from cultivation in vegetable growing areas in the general vicinity of Santiago and is now growing as a weed, probably largely as an annual, along irrigation ditch banks and in other places with adequate soil moisture. Windblown pollen from such plants and seed carried by irrigation water could be sources of contamination of sugarbeet material under certain conditions. It is conceivable that the annual tendency in the breeding lines resulted in part from such contamination. It also is conceivable that natural selection over a long period of time has resulted in the development of substantial yellow wilt resistance in the "wild" chard, and that contamination by such material has contributed resistance to the sugarbeet breeding program. Although such a beneficial role is purely hypothetical at present, the possibility that resistant genotypes occur among wild chard populations in the vicinity of Santiago deserves thorough study. Exploration of this matter is planned.

It is unclear whether factors mentioned in the preceding paragraphs adequately explain the annual tendency in the yellow wilt project material. In any case, the question arises as to whether a genetic linkage or some other causal relationship exists between yellow wilt resistance and the annual character. In our opinion, if some such relationship exists, it is not sufficient to interfere seriously with the selection and breeding program. Evidence in support of this conclusion may be observed in Tables 2, 3, 4, and 5.

The results presented in this report show conclusively that measurable progress has been made in the program of breeding sugarbeet for resistance to yellow wilt, and they indicate that further progress can be made. The apparent resistance of an introduction of *B. maritima* from Wembury Bay, England, suggests the possibility that valuable genes for resistance may be transferable to sugarbeet from that introduction and from other introductions of that wild species.

The long incubation periods in the insect vector (*P. exitiosus*) and the sugarbeet, and the erratic results of attempted inoculations of sugarbeet plants by means of cultures of that vector have interfered with breeding and other yellow wilt research in the past (3, 4, 6). The recent work of Urbina-Vidal and Hirumi (9), indicating the possibility of both virus and MLO involvement in the expression of symptoms, may represent an important step toward a better understanding of the disease and some of the frustrations of the past. A vigorous program of etiological research could lead to the development of more effective as well as more efficient methods of breeding for yellow wilt resistance.

## Summary

Conclusive evidence was obtained in field tests of 1972-73 and 1973-74 at the Estación Experimental La Platina, near Santiago, Chile, that measurable progress had been made in breeding sugarbeet for resistance to yellow wilt. The level of resistance attained thus far in breeding lines is not high, but the evidence strongly indicates that further progress can be made.

Typically, yellow wilt infection interferes seriously with seed production. Consequently, in the past, infected sugarbeet plants with some evidence of resistance, as appraised at the end of the vegetative growth

period, generally produced very little or no seed under the most favorable agronomic conditions. In 1972, antibiotic treatments were used with apparent success in promoting seed production by a limited number of selected (infected) plants that had been left undisturbed in the 1971-72 evaluation plots at La Platina.

Until 1973, all attempts to obtain seed from sugarbeet plants that showed definite yellow wilt symptoms, at or near the end of the vegetative growth period, and subsequently were transferred from the evaluation and selection plots to other locations, failed completely. With refinements in techniques, relatively satisfactory seed yields were obtained from selected (infected) plants that had been removed from the evaluation and selection plots in September (i.e., near the end of the winter), 1973, and treated repeatedly with the antibiotic, Terramycin. Thus, this much-needed breeding technique, heretofore unusable, now appears to be available to the breeding program.

In early selection and breeding for yellow wilt resistance in Argentina and Chile, it was concluded that plants without symptoms of the disease at the end of the vegetative growth period, under severe yellow wilt exposure, were simply escapees and consequently of little or no value for resistance breeding purposes. Evidence presented in this report indicated that, for at least some of the current breeding material, such plants may possess genes for resistance and should not be excluded from the breeding program.

One of three introductions of *B. maritima* appeared to have relatively high resistance to yellow wilt. This observation suggested that a useful but as yet untapped source of genes for resistance may exist in this wild species.

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