DISEASE, PEST, AND STRESS RESISTANCES AVAILABLE IN COMMERCIAL TYPES

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ABSTRACT

Results obtained from Western Regional and Tri-State variety trials, grower trials, and disease nurseries the past two years indicate the USDA ARS potato breeding and evaluation program at Prosser has been successful in developing and identifying multi-resistant lines whose performance compares favorably with Russet Burbank and Shepody, which are commonly grown in the Northwest. Use of these lines would make it possible to reduce use of pesticides in commercial potato production, reduce grower risks and losses, increase grower profits, improve marketability of U.S. grown potato products in foreign markets, and improve quality of potato products available to consumers. To illustrate the type of multi-resistant lines now available for use as possible cultivars by the potato industry and as parents in breeding programs, the performance of four promising lines, AO8478-1, A81286-1, AO84275-3 and AO80432-1, is discussed in detail. These are all derived from crosses made in the USDA, ARS breeding program at Aberdeen, Id. Three were selected from progenies grown in Oregon.

INTRODUCTION

Potato breeding program at Prosser

A USDA-ARS potato breeding program has been conducted at Prosser, Wa., the past 35 years, supervised by Dr. William Hoyman the first 19 years and since 1976 by the author. This program will apparently be discontinued when I retire in October 1993, unless the potato industry convinces congress and administrators it should be continued. This presentation will be a brief, condensed final report of this long term breeding effort.

During recent years, particular emphasis has been placed on introducing resistances to diseases, pests, and stresses into potato types useful to the Northwest potato industry (1 to 25). The overall objectives have been to identify genotypes that would allow reduced use of pesticides, water, and fertilizers; result in reduced risks associated with potato production; increased profits to growers, processors, and packers; and would provide consumers with better potatoes to eat. The Irrigated Agriculture Research and Extension Center near Prosser is particularly well adapted to breeding for such resistances.

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Breeding progress has been hindered by the complexity of the problems, the difficult objectives and lack of well-adapted parents with high levels of resistance. Recent results in the coordinated Western Regional breeding and evaluation program indicate that our efforts at Prosser have resulted in development and selection of promising multi-resistant breeding parents (7, 14 to 25). These are particulary well adapted to Columbia Basin growing conditions; producing very high total and No. 1 yields with excellent quality when allowed to grow full season and express the benefits of their virus and early dying resistances. Some lines have horticultural potential that might make them useful as commercial cultivars. Generous financial support by the Washington State Potato Commission and continuing cooperation, interest, patience, and encouragement by many in the Washington state potato industry have made this progress possible. The multi-resistant germplasm described herein should pay large dividends for all aspects of the potato industry in the future.

Difficulty of developing multi-resistant cultivars

Large breeding programs in the major potato growing regions of the USA have had very limited success in combining all the genes (horticultural characteristics) needed to produce "gene packages" (cultivars) that offer significant improvements over older, established cultivars, like Russet Burbank (RB). This is true even though older cultivars have many faults and leave much room for improvement. Combining all essential horticultural characteristics into one clone is a formidable task when breeding a vegetatively propagated tetraploid crop like potatoes. Trying to do this while, at the same time, adding resistances to diseases, pests and stresses makes the task many fold more difficult, laborious, and time consuming.

Breeding technique developed to emphasize resistances

We developed a breeding technique involving mass intercrossing within a group of parents all having one thing in common, that being at least some degree of resistance to a particular disease or pest along with one or more desirable horticultural characteristics (1,4,8,11). Several such intercrossing groups, each emphasizing resistance to a particular disease or pest, were set up each year at Prosser. First generation seedlings, produced from the bulked true seed from each mass cross, were screened under severe disease exposure, to select progeny plants in which resistance to that disease had been retained or enhanced (1,2,3). The true seed was planted directly into a field disease nursery or used to grow transplants which were planted in the nursery (1,2,5,6,12,13). Tubers were harvested from plants expressing worthwhile resistance to the disease in question and producing good yields of acceptable tubers (1,2,6,9,12). The tubers from each selected plant were retained for further evaluation only if they proved to have acceptable specific gravity, bruise resistance and good storability (9,10). The tubers of these selected clones were cut the next spring, further selected for freedom from internal blemishes, and then used for seed. This seed was planted again in the same disease nursery to evaluate the performance of each clone when chronically infected and/or when being exposed to that disease or pest a second year.

Those producing well after two years of severe disease exposure were freed of viruses and other diseases by meristem culturing so disease-free seed could be produced for further testing.

Primary emphasis placed on resistances

By placing primary emphasis on breeding and selecting for disease resistance and then examining horticultural characteristics in resistant progenies, it was possible to develop and identify remarkable levels of resistance within domestic potatoes adapted to production in the Northwest (20 to 25). By screening over one million clones, we found high levels of resistances to most diseases, pests and stresses troubling the potato industry. During the last several years we have characterized and quantified the value of these resistances (13 to 19). Much progress has been made in combining several of these resistances into individual clones that have sufficient horticultural potential to be evaluated in regional variety trials. These accomplishments would normally require a number of breeding programs to attain or the successive contributions of several generations of breeders.

Sources of resistance

We initially concentrated on resistances to potato leafroll virus, potato virus Y, and the early dying diseases, primarily Verticillium wilt and early blight. Intercrossing groups were set up for each of these four diseases (1,3,4,8,11). Existing literature was reviewed and known sources of resistance to each were collected from breeding programs in the United States, Canada, and other countries in the world. We found impressive levels of resistance available in domestic potatoes, but the most effective resistances were usually in round white types, poorly adapted to the Northwest (1,3,7,8).

Three sources of segregating progenies were screened for resistances. Highly resistant, poorly adapted, round whites were crossed or mass intercrossed with long russets adapted to the Northwest, especially cultivars or breeding lines that were known to process well and had at least low levels of resistance. Pedigree crossing was done at Aberdeen, Id., and mass intercrossing was done at Prosser. Seed derived from both types of crossing was used to produce first generation progenies that were screened in disease nurseries. We also collected numerous second and third generation clones from single hill plantings and preliminary evaluation trials conducted in the states involved in the Western Regional evaluation program. These were also evaluated in disease nurseries. All three types of protenies proved to be fruitful sources of clones with valuable disease, pest, and stress resistance (20 to 25).

Other important attributes of multi-resistant lines

As clones with high levels of resistance to a given disease were identified, their responses to other diseases and pests were tested and noted. Some were found to be highly resistant to all four diseases originally targeted.

In addition, several have high levels of resistance to Sclerotinia wilt, powdery mildew, common scab, powdery scab, black dot, Colorado potato beetles and spider mites (7,15,20,22,23). Many can be successively grown without applying aphicides or fungicides (16 to 19). A few have useful resistance to Columbia root-knot nematode (7). As these additional resistances were identified, inter-crossing groups and disease nurseries were also set up for scab, Colorado potato beetle and Columbia root-knot nematodes.

Because of their vigor, these multi-resistant lines can be grown with minimal or no use of herbicides. All offer a marked improvement over RB in stress resistance and require less irrigation and fertilization to produce a full crop. Most produce higher total and No. 1 yields, have higher solids and less internal blemishes than RB and process as well. Some bruise as bad or worse than RB. This bruising is often associated with high solids. Few, if any, of these lines store as long as RB, but most will store well to mid-spring without sprout inhibitors. Sprout inhibitor studies need to be conducted on these resistant lines to determine how long their storage season can be extended. When compared with these resistant types, RB would probably still be the cultivar best adapted to long-term storage. Not many have tubers that are as long as RB nor have as many eyes on tubers.

MATERIALS AND METHODS

Regional and Tri-State trials

During the 15 yrs the Western Regional Trials have been conducted, we have entered 25 lines for evaluation. Performances of 12 of these have been evaluated the past 3 yrs by cooperators in coordinated Regional and Tri-State trials. Six were judged promising enough to be continued in 1993 trials, along with five new lines we entered. These coordinated trials, conducted over a wide area extending from Texas to Washington, thoroughly evaluate all entries for growth, production, handling, and processing characteristics, including their response to important diseases.

Trials in commercial potato fields

In addition to regional trials, which evaluators usually conduct on experiment stations, they also conduct trials in commercial potato fields. Promising lines, where seed is available, are tested in the "real world", comparing their performance to accepted commercial cultivars. In 1992, we entered 12 advanced lines in seven grower trials located throughout the Columbia Basin area of Washington and Oregon. Four of these trials were conducted in cooperation with Dr. Robert Thornton and assistants of Washington State University and Dan Hane and others associated with Oregon State University. Another 18 less advanced, multi-resistant lines were also evaluated in four of these grower trials. Generally these trials were conducted in center-pivot irrigated circles of Russet Burbank under RB cultural conditions.

Using minimal pesticides to determine value of multi-disease resistance

Also in cooperation with Thornton and Hane, trials were conducted at Othello and Hermiston in which commercial cultivars and 28 multi-resistant lines, from the three sources discussed above, were grown with minimal pesticide applications. These trials included those resistant lines entered in regional and grower trials. They were harvested in October so the value of the resistances of the 28 resistant lines had time to be expressed. In cooperation with Sunspiced, Inc., a company that produces dehydrated potatoes, a similar trial was conducted to determine how much dry matter per acre these multi-resistant types can produce.

RESULTS AND DISCUSSION

Results of Regional and Tri-State Trials

The performance of multi-resistant entries in coordinated Regional and Tri-State trials compared favorably with that of RB and other commercial cultivars in total and No. 1 yields, tuber size, and specific gravity (Figs. 1a, 1b). This was true even though the trials were harvested when RB and other commercial checks were dead and ready for harvest but multi-resistant entries were still healthy and bulking.

These entries also generally performed well in post harvest evaluations by Loretta Mikitzel and other evaluators in the Tri-State group (Tables 1,2). Based on results of Tri-State and Western Regional trials and grower and disease nursery trials, four multi-resistant lines, AO8478-1 (Line 78), AO84275-3 (Line 275), A81286-1 (Line 286), and AO80432-1 (Line 432), were judged especially promising. They are being further evaluated in 1993 trials. A summary of the performances of these four in 1991 and 1992 trials is given below.

Summary of performance of Line 78

Line 78, has a medium-sized plant which grows very prostrate. It is resistant to PVY, Verticillium wilt, early blight, and common and powdery scab, but is susceptible to PLRV. In 1991 and 1992 trials, Line 78 often produced higher total yields than RB, and consistently had higher No. 1 yields and a higher proportion of large tubers (Figs. 2a, 2b). Compared to RB, Line 78 had similar specific gravities in most trials (Figs. 2a, 2b), fewer knobs, less growth cracking, similar shatter bruising, more blackspot bruise, similar incidence of hollow heart, more internal brown spot, somewhat more reducing sugars and darker fry colors, but higher percent acceptable fries, less sugar ends on fries, similar cooking time, similar acceptance by taste panels, more sprouting in storage, similar rot losses, and lower overall rating (Tables 1 to 5). Tubers of Line 78 have an unusually large number of eyes. This multi-resistant line should be evaluated as a medium early to midseason type, useful for either out-of-field processing or fresh market. It is not adapted to long-term storage.

Summary of performance of Line 275

Line 275, which has a medium-sized plant, shows high levels of resistance to PLRV, PVY, Verticillium wilt, early blight, and common and powdery scab. Compared to RB, in 1991 and 1992 regional trials, Line 275 generally had lower total yields, higher No. 1 yields and smaller tuber size (Figs. 3a, 3b and Tables 1, 2). These trials were harvested before Line 275 fully benefited from its resistances and demonstrated its potential. It sets more tubers than RB and requires a longer growing season for this heavy set of tubers to enlarge to acceptable size and shape and separate easily from stolons. In longer season trials, this line produces unusually high yields of top quality tubers with few oversize, very high percent No. 1's, and high specific gravity and excellent eating quality. Compared to RB, Line 275 has smaller, shorter, more uniform tubers, with less knobs, heavier russeting, less growth cracking, similar shatter and blackspot bruising, and less hollow heart and vascular necrosis (Tables 1, 2, 4). Line 275 had similar levels of solids but less reducing sugars than RB before or after storage and usually had lighter fry colors, fewer sugar ends, and higher percent acceptable fries (Tables 1, 2, 3). It usually cooked faster than RB and rated as high in taste panel evaluations (Table 1, 4). It is higher in protein and vitamin C than RB and lower in glycoalkaloids (Table 2). The dormancy of line 275 is shorter than RB and it is damaged more by bacterial or Fusarium rots than RB, especially when immature tubers are harvested from under green plants (Tables 1, 5). In a trial near Hermiston, toxic seedpiece syndrome caused numerous plants of Line 275 to die, expressing symptoms similar to blackleg. This line received higher overall ratings for post-harvest characteristics than RB when tubers were harvested from the Columbia Basin area of Washington and Oregon, but lower than RB for tubers harvested from Idaho. This is probably because of its need for a longer growing season, like that in the Columbia Basin, to fully mature and express its potential. This line should be evaluated as a late season processing or fresh market type, adapted to only short-term storage. It also has potential of producing large yields of dry matter per acre for the dehydrated potato industry.

Summary of performance of Line 286

Line 286 produces large, vigorous plants and is resistant to PLRV, PVY, Verticillium wilt, early blight, and common scab. It had higher total and No. 1 yields, and larger tubers than RB in the 1991 and 1992 main season regional trials (Figs. 4a, 4b, and Tables 1, 2). Its specific gravity was inconsistent, sometimes higher and other times lower than that of RB (Figs. 4a, 4b). Compared to RB this line has larger, shorter, lighter russeted tubers, with less knobs, less growth cracking, similar shatter bruising, less blackspot bruising, and less hollow heart and vascular necrosis (Tables 1, 2, 4). At harvest tubers of Line 286 are low in reducing sugars, producing fries that cook faster and are equal or better than those of RB in color and taste panel preference, with fewer sugar ends, higher protein content, and lower glycoalkaloids (Tables 1, 2, 4). Tubers of this line resist rotting and store well, though their dormancy is shorter than that of RB and they tend to accumulate some reducing sugars in cold storage (Tables 1, 3, 5). Tubers of Line 286 are of Kennebec type, having a buff to light russet skin that does not set well in early harvests.

Other than its effect on appearance, however, skin sloughing of this line should not be a problem in processing. Total and No. 1 yields and tuber size are usually equal or superior to Shepody in early harvests (Fig. 4c). Its solids are somewhat lower than Shepody in early harvests but because of low reducing sugars it processes into French fries equal in color and quality to Shepody (Table 6). Because of multi-disease resistance, Line 286 has remarkable yield capacity if allowed to grow full season in regions like the Columbia Basin. Tubers become very large later in the season with undesirable appearance, though most will be graded as No. 1's for processing. As the growing season progresses, solids in Line 286 improve to a level equal to or better than RB. This line should be evaluated as: (1) an early season Shepody type, (2) a main season, out-of-field processing type, or, (3) if grown full season, for use in the dehydrated potato industry.

Summary of performance of Line 432

Line 432 produces a medium-large plant, resistant to PVY, Verticillium wilt, and heat and water stress. It is moderately resistant to PLRV and early blight, and susceptible to common scab. In the 1991 and 1992 Tri-State trials, Line 432 generally had lower total yields than RB, similar tuber size and higher No. 1 yields and specific gravity (Figs. 5a, 5b). Tubers are smooth, have a light russet skin, good length, no knobs, and seldom growth crack (Tables 1, 2). Compared to RB, this line sometimes had more shatter and blackspot bruising but less hollow heart (Tables 1, 2, 4). It sprouted earlier than RB in storage and was damaged more by bacterial rots (Tables 1, 5). Line 432 had levels of reducing sugars and French fry colors similar to RB, both at harvest and after storage, but often had a lighter fry color, less sugar ends, and higher percent acceptable fries (Tables 1, 2, 3). It sometimes did not rate as high in taste panel evaluations (Table 4). Its cooking time was similar to RB. This line should be evaluated as a main season processing type to be processed at harvest or after short-term storage. Because of extraordinary stress resistance, it should be tried in areas where irrigation is not used and/or drought stress is encountered.

Performance of these four lines in 1992 grower trials

In a trial on Stetner Farms near George, planted April 21 and harvested September 15, a 148-day growing season, three of the four resistant lines, when compared with RB, produced higher total and No. 1 yields, a higher proportion of tubers over 10 oz, and higher specific gravities (Fig. 6). The increases in total yields ranged from 26 cwt/A for line 286 to 93 cwt for Line 78. Increases in No. 1 yields were even more impressive, ranging from 75 cwt for Line 286 to 137 cwt for Line 78. Improvements in specific gravities ranged from 4 points for Line 78 to 15 points for Line 275. This harvest was too early for Line 275, it had not sized up yet. RB was mostly dead at harvest but these resistant lines were still green and bulking (Fig. 7). When Dr. Dennis Johnson tested juice from RB and these resistant lines for the presence of propagules of Verticillium and Colletotrichum, the cause of black dot, there were many more disease propagules in RB (Fig. 8).

In a trial on McNary Farm, near Plymouth, planted April 27 and harvested September 30, a 156-day growing season, three of the four resistant lines again produced higher total and No. 1 yields, a higher proportion of tubers over 10 oz, and much higher specific gravities (Fig. 6). Increases in total yields ranged from 7 cwt/A for Line 78 to 122 cwt for Line 432. Increases in No. 1 yields were again even more impressive, ranging from 54 cwt for Line 78 to 167 cwt for Line 432. It is not clear why Line 286 did not produce its usual high yields in this trial. It and the other resistant lines were still healthy and actively bulking at the time of harvest, while RB in the remainder of the field was completely dead.

The resistant lines had much better specific gravities than RB, ranging from 8 points higher for Line 286 to 28 points higher for Line 275. Since growers in the Columbia Basin have problems producing the specific gravities in RB desired by the French fry industry, these resistant lines offer a real advantage in this regard.

In a trial on Sunheaven Farms, south of Prosser, planted April 29 and harvested September 29, a 155-day growing season, all four resistant lines produced higher total yields, three of four had higher No. 1 yields, two of four a higher proportion of tubers over 10 oz, and three of four had higher specific gravities (Fig. 6). Increases in total yield ranged from 13 cwt/A for Line 78 to 160 cwt for Line 432. Increases in No. 1 yields ranged from 11 cwt for Line 78 to 178 cwt for Line 432. Improvements in specific gravity ranged from 2 points for Line 78 to 19 points for Line 275. The total yield of Line 275 was higher than RB but it needed another 3 wk of bulking to develop acceptable tuber size and shape for processing. Again the resistant lines were still bulking at the time of harvest.

A trial was also conducted on the AgriNorthwest Research Farm near Plymouth. This was a long season trial, planted April 8 and harvested October 20, a growing season of 196 days. Unfortunately, severe heat stress during the bulking season and a devastating Colorado potato beetle infestation late in the season reduced the number of growing days considerably, so yields of neither RB nor the resistant lines reached their potential. However, compared to RB all four resistant lines produced higher total and No. 1 yields, three of four had a higher proportion of tubers over 10 oz, and all had higher specific gravities (Fig. 6). Increases in yield ranged from 9 cwt/A for Line 286 to a remarkable 211 cwt for Line 432. Because of the more severe effects of heat stress on RB than on these relatively stress resistant lines, the increases in No. 1 yields were dramatic, ranging from 69 cwt for Line 275 to 298 cwt for Line 432. It was in this trial that a high level of heat and water stress resistance of Line 432 became evident. On a day when temperatures were near 120°F, this line was standing up with a fresh green appearance in all four reps when other lines around it, including RB, were dull colored and severely wilted, even though the soil was moist. This stress resistance resulted in Line 432 having a No. 1 yield more than double that of RB. Improvements in specific gravity over RB ranged from 4 points for Line 286 to 26 points for Line 275.

Results of these four grower trials, conducted in various parts of the Columbia Basin on differing soil types, showed that these four multi-resistant lines offer advantages over RB in total and No. 1 yields, tuber size, and specific gravities. These advantages were expressed even though the trials were all conducted in RB circles, under RB cultural conditions, and harvested when RB died. At this time the resistant lines were still healthy and increasing in yields and quality. When allowed to grow for another 2-3 wks they are much superior to RB. There are also undoubtedly cultural practices, other than those used for RB, that would be advantageous for these resistant lines and for growers. After conducting dozens of performance trials on these lines under a wide range of cultural conditions, we are convinced they will produce full crops with less fertilization and irrigation and less use of pesticides of all kinds. The consistent advantages of these resistant lines in specific gravities and grade should be very important for growers, processors and packers in the Columbia Basin.

Performance of four resistant lines in long season trials

The value of the resistances of these four lines was demonstrated by results from two long season, minimal pesticide trials conducted at Othello and Hermiston (Fig. 9), and a long season, "dry-matter" trial conducted by Carl Henrickson, Sunspiced, Inc., near Moses Lake. At Othello, we did not introduce sources of viruses, some pesticides were applied, and the trial was planted where there was minimal exposure to Verticillium wilt. Consequently, disease exposures were not severe. As a result the total yield of RB was unusually high, over 900 cwt/A, but Line 78 was equally high, and Lines 275 and 286 produced even higher yields, 1069 and 1273 cwt, respectively (Fig. 9). All four resistant lines produced much higher No. 1 yields than RB. Increases in this important attribute ranged from 109 cwt for Line 275 up to 241 cwt for Line 286. Compared to RB all had a much higher proportion of tubers larger than 10 oz. Lines 78 and 286 had specific gravities similar to RB, but Line 432 was 12 points higher and Line 275 was 18 points higher.

In the Hermiston trial, every fifth row through the field was planted with tubers known to be infected with PLRV and PVY viruses, the field was sprayed only with pyrethroids for Colorado potato beetle control, and the plants were severely exposed to Verticillium wilt and early blight. Disease exposure started early and was severe throughout the season. Line 432 was inadvertently left out of this trial. The other three resistant lines produced much higher total and No. 1 yields, higher proportion of tubers over 10 oz (RB produced none), and higher specific gravities (Fig. 9). Increases in total yields ranged from 156 cwt/A for Line 78 up to 536 cwt for Line 286. Line 286 produced almost three times as much total yield as RB and over four times as much No. 1 yield. Improvements in specific gravity over RB ranged from 7 points for Line 286 up to 19 points for Line 275.

Unfortunately, RB was not entered in the "dry-matter" (DM) trial conducted by Sunspiced. The PLRV resistant cultivar Abnaki, which usually yields as much or more than RB, yielded 554 cwt/A with specific gravity of 70, which would result in 5.1 tons of DM/A.

Line 286 yieldsed 776 cwt with specific gravity of 89, which would result in 8.8 T of DM/A, and Line 275 yielded 776 cwt with specific gravity of 112, which would result in 10.8 T of DM/A. Therefore, when allowed to grow full season, Line 286 would produce over 50% more DM/A than would be expected from RB, and Line 275 would produce more than twice as much. Incidentally, other multi-resistant lines with less desirable tuber type, known from past experience to produce high yields of high solids tubers, produced from 10.4 to 14.5 T of DM/A in this trial. This is equivalent to wheat or corn crops of 500 to 700 bu/Ac! Some of these multi-resistant lines should be useful for production specifically for use in the dehydrated potato industry or for production of ethanol fuel.

It is important to note, however, that a grower could not harvest all his potatoes in October to take advantage of high yield potentials of multi-resistant types. The possibility of damaging frosts, fall rains and bruising problems associated with harvests under cold conditions allows only limited harvesting this late. The very large tuber size and excessive plant growth associated with such high yields can also be problems. Incidentally, results of studies we conducted several years ago indicated that large plants associated with disease resistance make good cattle feed or would add to the ethanol producing potential of potatoes.

Performance of four resistant lines in disease nurseries

The four multi-resistant lines emphasized in this report became infected with all common potato viruses and early dying diseases when grown in disease nurseries. Since they were planted in fields thoroughly infested with soilborne diseases, were grown without use of aphicides and fungicides, and virus diseases were enhanced by interplanting virus-infected seed tubers, very severe disease exposures occurred in both 1991 and 1992. However, compared to RB and other commonly grown cultivars in the Northwest, fewer plants of these resistant lines became infected, symptoms occurred later in the season, and symptoms were generally not as severe (data not shown). Because of greatly reduced disease damage, these lines remained relatively healthy much longer in the fall and continued to improve in yields and quality (Fig. 10). In early September harvests, they had total yields similar to RB but were often superior to RB in No. 1 yields and specific gravities. In later harvests, in early October, they were consistently much superior to RB in total and No. 1 yields and specific gravities. The extremely severe disease conditions in these nurseries would not be encountered in commercial production. Under relatively mild disease exposures normally encountered in commercial fields, there would be no need for growers to apply aphicides or fungicides when growing these resistant types. Occasional sprays with pyrethroids may be needed to control Colorado potato beetles.

Performance of four resistant lines in chronic disease trials

When virus diseased tubers of RB and the four resistant lines were used as seed to plant chronic disease trials, the value of resistance was dramatically demonstrated.

Seed tubers of RB infected with either PLRV or PVY resulted in crops that produced few tubers of any kind and no marketable tubers (Fig. 11). Chronically infected seed tubers of other cultivars grown in the Northwest resulted in similar poor performances, with the exception of Shepody, which produced a fair crop in chronic trials (data not shown). Resistant lines all produced at least a moderate crop and Line 286 produced almost a full crop in both 1991 and 1992 chronic trials (Fig. 11). Growers in countries with well-established seed certification programs would not knowingly plant infected tubers but it would be comforting to know diseased tubers inadvertently planted would result in little or no losses. In underdeveloped nations where growers commonly plant non-certified seed, often badly infected with viruses, these levels of multiple resistance would have great value.

Performance of resistant line in other regions

Seed of three of these resistant lines, 78, 275 and 286, was sent to Wisconsin and North Dakota for trials. These resistant lines performed well in these areas also (Tables 12, 13). In most of the trials in which these lines were entered they produced higher total and No. 1 yields than RB and other commercial cultivars. This surprised us, since these are areas with relatively short growing seasons. Apparently, the area of adaptability of these lines extends beyond the Northwest.

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Table 1. Results of postharvest evaluation of RB and seven multi-resistant lines in 1991 Tri-State Trials in Washington, Oregon, and Idaho. Overall averages of three replicated trials extracted from report by Loretta Mikitzel and/or the 1991 Tri-State report.

	78	224	275	286	432	478	622	RB
Tuber size (oz)	7.9	7.4	5.8	9.4	6.5	7.6	7.9	6.6
Growth cracks[v]	4.3	4.9	5.0	3.7	4.6	4.8	5.0	4.1
Shatter bruise[v]	3.9	3.9	3.6	4.2	3.9	3.4	3.6	4.0
Blackspot bruise[v]	3.8	4.2	3.9	4.4	3.8	4.1	3.9	3.8
% Blackspot	62	14	46	32	54	28	43	54
% Hollow heart	10	16	2	1	5	0	9	13
% Internal brown spot	21	0	0	3	0	0	0	0
Fry color 45° stor[w]	1.6	1.3	0.7	0.8	0.7	1.1	0.7	1.1
Reflectance early[x]	53	50	62	64	59	71	56	58
Reflectance late[x]	41	45	46	47	46	44	55	44
Reflectance 44° stor[x]	30	34	38	35	34	33	44	32
Reflectance 48° stor[x]	37	30	38	41	42	40	45	38
% Sugar ends	20	0	5	6	4	17	1	23
% Accept no storage	67	97	89	75	86	64	100	61
% Accept 44° storage	14	53	55	44	44	34	64	23
% Accept 48° storage	33	81	53	55	61	44	70	39
% Solids	18	17	20	17	22	19	23	20
% Reduce sug no stor	2.1	2.0	1.5	2.2	1.2	2.7	1.1	1.8
% Reduce sug 44° stor	4.1	3.6	2.7	3.8	3.3	4.5	1.5	3.2
Cook time (min)	18	18	17	22	16	24	20	17
Taste rating[y]	3.1	2.7	3.4	3.3	3.4	3.4	3.5	3.2
% Sprouting	100	57	100	98	91	68	28	57
% Rot[z]	17	25	31	9	12	11	13	17

[v] 1-5 score with 1 = severe, 5 = none.
[w] 0-4 scale with 0 = light, 4 = dark.
[x] Photovolt readings, high reading = lighter fry colors, reading <20 = unacceptable.
[y] Taste panel ratings, 1-5 scale, 1 = very poor, 5 = very good.
[z] Sample of tubers inoculated with *Erwinia*, incubated 24 hr, room temp, high humidity, wash out rotted tissue, and calculate percent fresh weight lost.

Table 2. Results of post-harvest evaluation of RB and eight multi-resistant lines in 1992 trials. Overall averages computed from reports of L. Mikitzel and/or three Tri-State and 14 Western Regional replicated trials, using data from those locations which measured that characteristic.

	Tri-State entries					Western Regional entries				
	RB	37	78	216	432	RB	275	286	473	478
Tuber sz (oz)	8.8	6.2	8.2	7.7	6.9	6.4	5.0	7.3	7.6	7.5
Tuber shape[x/]						4.3	3.2	3.1	3.2	3.5
Shape uniformity[x/]						3.5	4.9	3.4	4.1	4.4
Knobs[x/]	3.0	5.0	4.9	5.0	5.0	3.7	5.0	5.0	5.0	4.9
Russeting[x/]						3.1	4.2	2.4	4.2	3.9
Skin set[x/]						4.6	4.8	1.7	3.3	3.7
Growth crack[x/]	3.1	4.7	4.0	4.9	4.4	4.0	4.9	4.2	4.4	5.0
Shatter bruise[x/]	3.6	3.9	3.6	3.8	2.8	4.5	4.3	4.6	4.1	4.1
Blackspot bruise[x/]	3.3	2.9	2.8	2.5	3.3	4.2	3.9	4.2	4.7	4.3
% Blackspot	4.0	1.5	1.5	2.5	3.0	1.3	0	0.5	0	0
% Hollow heart	5.0	11.3	3.3	19.8	1.0	7.0	2.6	0.8	2.3	0.9
% Vascular necrosis						6.2	1.3	2.0	0.3	4.9
% Internal brown spot	2.3	1.0	14.0	0	0	0.4	0	0.3	0.3	0.1
Fry color[y/]	0.6	0.8	0.7	1.1	0.9	1.1	1.3	1.7	1.3	1.6
Reflectance[z/]						35	46	43	43	44
% Sugar ends	10.5	7.5	7.5	2.0	4.5	17.8	17.5	6.0	8.2	8.3
% Solids						24	24	22	23	23
% Sucrose						0.7	1.1	0.7	1.2	1.0
% Reducing sugar						0.2	0.2	0.1	0.2	0.2
% Protein						4.2	5.7	5.6	6.1	5.7
Vitamin C (mg/100 g)						22	24	22	24	25
Glycoalkaloids (mg/100 g)						4	1	1	0	2

[x/]1-5 scale with 1 = round shape, poor uniformity, many knobs, no russeting of skin, poor skin set, much growth crack, shatter and blackspot bruising; 5 = long shape, good uniformity, no knobs, heavy russeting, good skin set, no growth cracks, shatter or blackspot bruising.

[y/]0-4 scale with 0 = light, 4 = dark.

[z/]Photovolt readings, higher readings = lighter fry colors.

Table 3. French fry colors and percent reducing sugars in RB and four multi-resistant lines grown in 1992 Tri-State (TS) and Western Regional (WR) trials in Washington, Oregon, and Idaho. Extracted from report by Loretta Mikitzel.

	Reflectance[z]			% Reducing sugars		
	WA	OR	ID	WA	OR	ID
Before storage						
RB-WR	30	33	43	0.7	2.7	1.6
275	36	35	43	0.8	1.5	1.6
286	27	31	41	0.5	2.1	2.1
RB-TS	43	33	45	1.7	1.3	0.8
78	30	30	41	2.0	2.0	1.2
432	38	31	43	1.9	0.8	1.1
48°F storage - 3 mo						
RB-WR	31	33	40	1.1	0.9	0.6
275	34	32	39	1.0	1.2	0.9
286	24	29	33	4.0	1.6	1.3
RB-TS	30	28	40	1.4	1.4	0.6
78	28	29	37	1.8	1.3	0.6
432	33	29	34	0.9	1.7	0.7
44°F storage - 3 mo						
RB-WR	25	26	34	3.5	2.6	0.9
275	27	25	28	2.3	2.8	2.4
286	18	22	31	4.5	3.4	2.2
RB-TS	38	28	38	3.4	1.3	0.9
78	33	25	33	2.9	2.6	1.2
432	34	24	34	2.8	2.9	1.4

[z]/Higher photovolt readings = lighter fry colors, reading <20 = unacceptable fries.

Table 4. Incidence of bruising and hollow heart in RB and four multi-resistant lines grown in 1992 Tri-State (TS) and Western Regional (WR) trials in Washington, Oregon, and Idaho. Extracted from report by Loretta Mikitzel.

	% Blackspot bruise			% Shatter bruise			% Hollow heart			Cooking time (min)			Taste panel[z]		
	WA	OR	ID	WA	OR	ID	WA	OR	ID	WA	OR	ID	WA	OR	ID
RB-WR	33	29	39	4.0	5.0	2.1	10	2	9	25	25	21	3.2	3.4	3.6
275	25	19	43	3.3	4.3	2.3	2	2	0	15	17	23	3.9	3.3	3.6
286	11	4	33	4.2	5.0	2.8	3	1	1	15	23	23	3.3	3.1	3.3
RB-TS	22	54	41	3.5	5.0	2.4	8	11	8	24	23	18	3.4	2.9	3.6
78	30	77	70	3.8	4.5	2.6	21	7	0	22	16	22	3.2	3.0	3.3
432	36	48	67	2.5	3.3	2.5	3	3	0	15	18	26	2.7	2.3	3.4

[z] Score 1-5, with 1 = poor, 5 = very good.

Table 5. Sprouting, rotting, and overall rating of RB and four multi-resistant lines grown in 1992 Tri-State (TS) and Western Regional (WR) trials in Washington, Oregon, and Idaho. Extracted from report by Loretta Mikitzel.

	Sprouted 40°F[x]			Sprouted 48°F[x]			% Bacterial rot[y]			Overall rating[z]		
	WA	OR	ID	WA	OR	ID	WA	OR	ID	WA	OR	ID
RB-WR	0	0	0	7	40	29	23	11	17	80	72	98
275	0	21	0	100	100	100	14	12	15	98	74	73
286	0	0	0	64	100	93	16	8	12	66	53	55
RB-TS	0	0	0	14	50	7	15	12	23	75	72	87
78	14	7	0	93	100	100	15	13	24	56	62	55
432	7	14	14	86	93	93	20	15	33	75	60	64

[x]Percent of tubers starting to sprout after 3 mos in storage at temperatures shown.
[y]Sample of tubers inoculated with *Erwinia* incubated 24 hr at 72°F in high humidity, wash out rotted tissue, and calculate percent fresh weight lost.
[z]Rating based upon all postharvest characteristics evaluated.

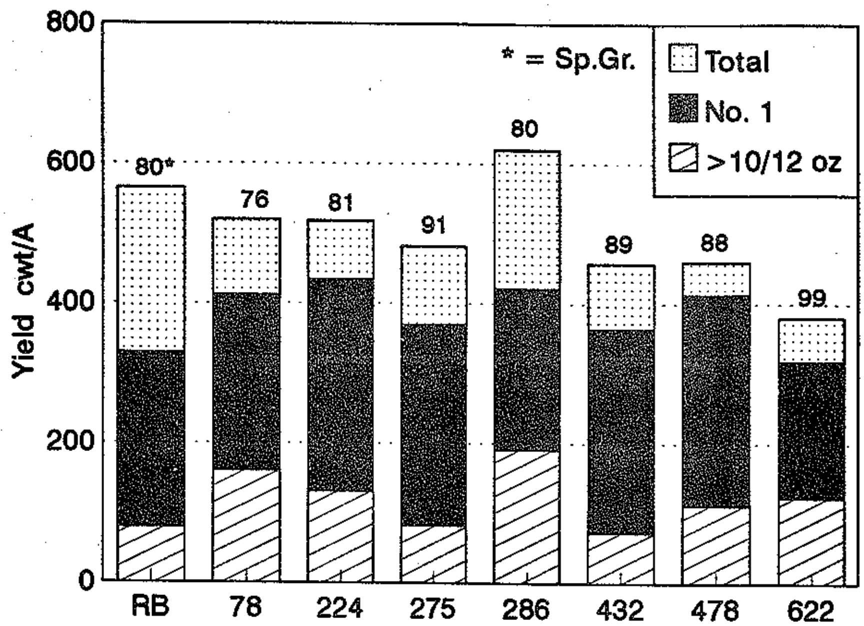
Table 6. Processability of A81286-1 compared to Shepody and Russet Burbank in 1992 early harvested trials.

Line	Location	Sp. Gravity (1.0--)	Reflectance[z]
A81286-1	Othello, WA	71	50
Shepody	Othello, WA	70	46
R. Burbank	Othello, WA	72	44
A81286-1	Hermiston, OR	60	44
Shepody	Hermiston, OR	65	47
R. Burbank	Hermiston, OR	67	40
A81286-1	Aberdeen, ID	71	48
Shepody	Aberdeen, ID	78	52
R. Burbank	Aberdeen, ID	78	46
A81286-1	Pasco, WA	64	42
Shepody	Pasco, WA	65	37

[z]Higher photovolt readings = lighter fry colors. In all cases 100% of fries were acceptable by USDA color standards.

Figure 1. Average total, No. 1, and >10/12 oz yields and specific gravities of multi-resistant entries in 1991 and 1992 Tri-State and Regional trials.

a. Results of 1991 Tri-State Trials conducted in Washington, Oregon, & Idaho.



b. Results of 1992 trials conducted at 10 locations in six western states.

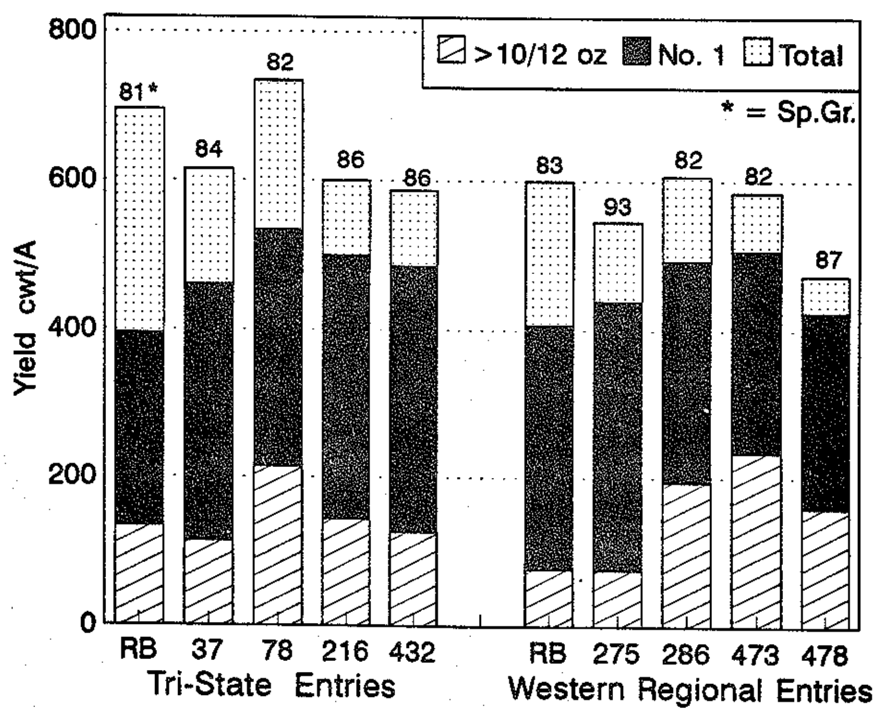
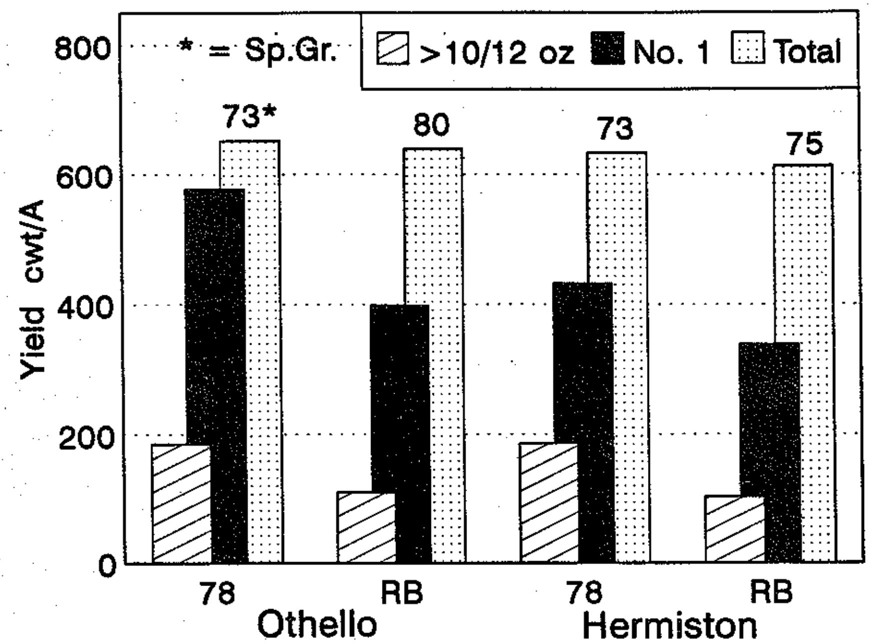


Figure 2. Average total, No. 1, and >10/12 oz yields and specific gravities of multi-resistant Line A08478-1 compared to Russet Burbank in 1991 & 1992.

a. Results of 1991 trials conducted in Washington and Oregon.



b. Results of 1992 trials in Washington, Oregon, and Idaho, including an early harvest trial at Aberdeen where Line 78 was compared with Shepody.

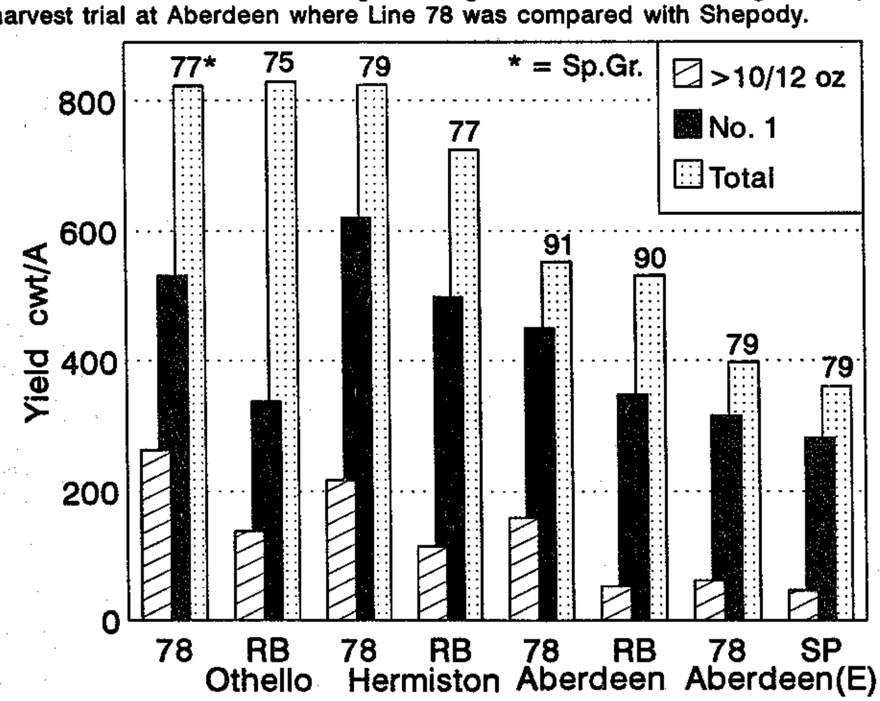
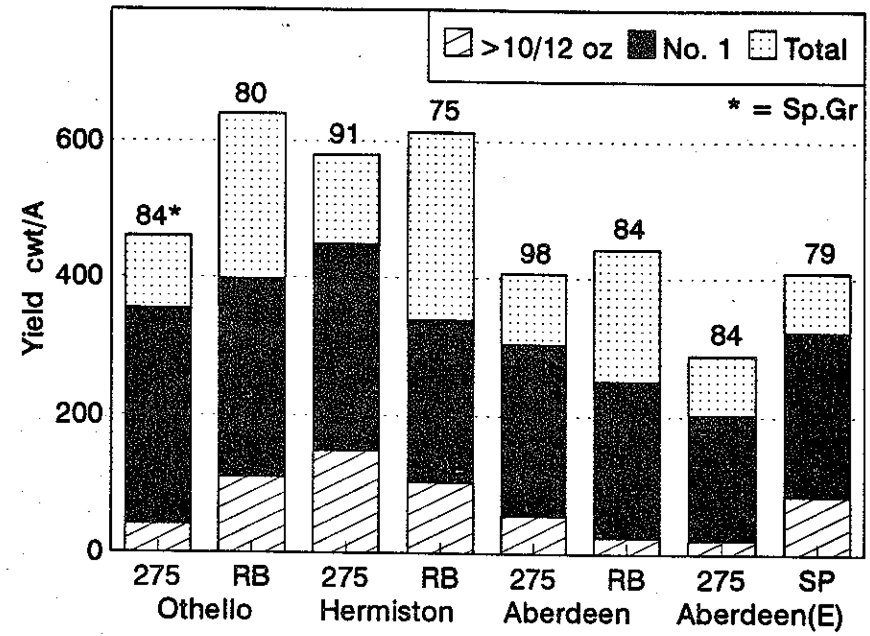


Figure 3. Average yields and specific gravities of multi-resistant Line A084275-3 compared to RB in Washington, Oregon and Idaho.

a. Results of 1991 Tri-State trials, including comparison with Shepody (SP).



b. Results of 1992 Western Regional trials at six locations in Northwest.

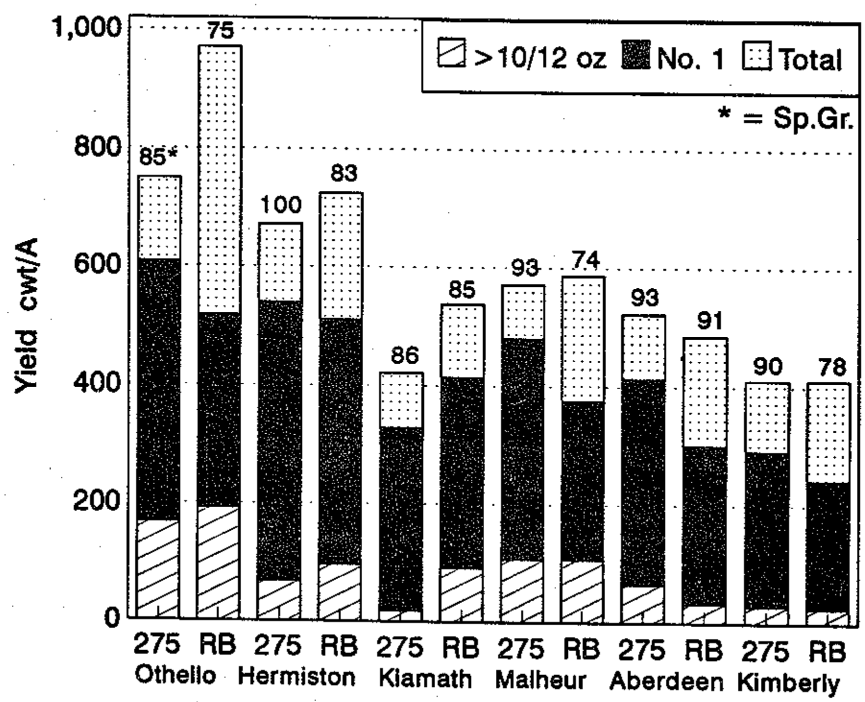
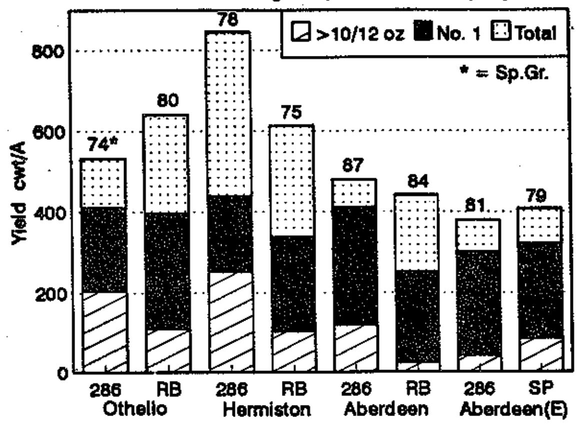
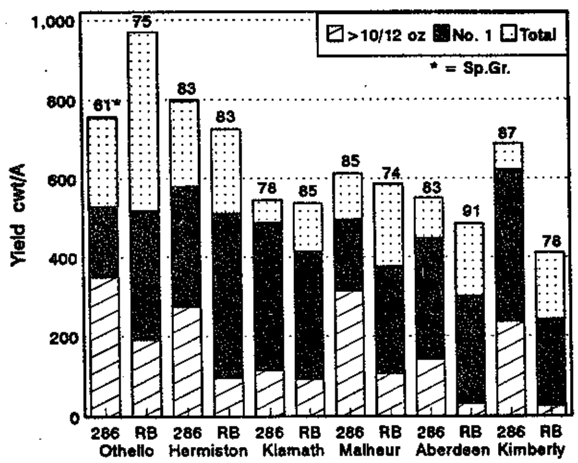


Figure 4. Average yields and specific gravities of RB and multi-resistant Line A81286-1 in Tri-State and Western Regional trials.

a. 1991 Tri-State trials, including comparison with Shepody.



b. Results of 1992 Western Regional trials at six locations in Northwest.



c. Results of 1992 early harvest Western Regional trials conducted in Washington, Oregon, and Idaho.

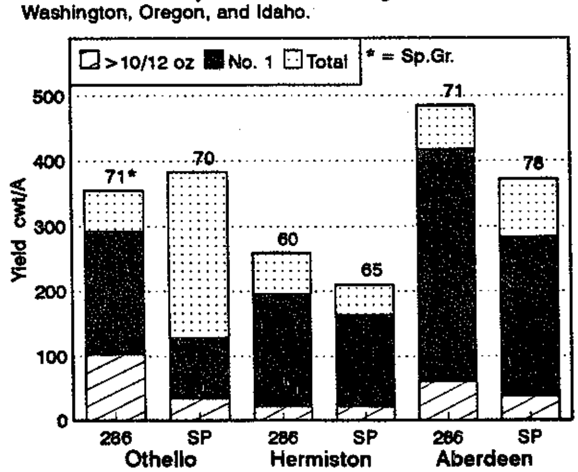
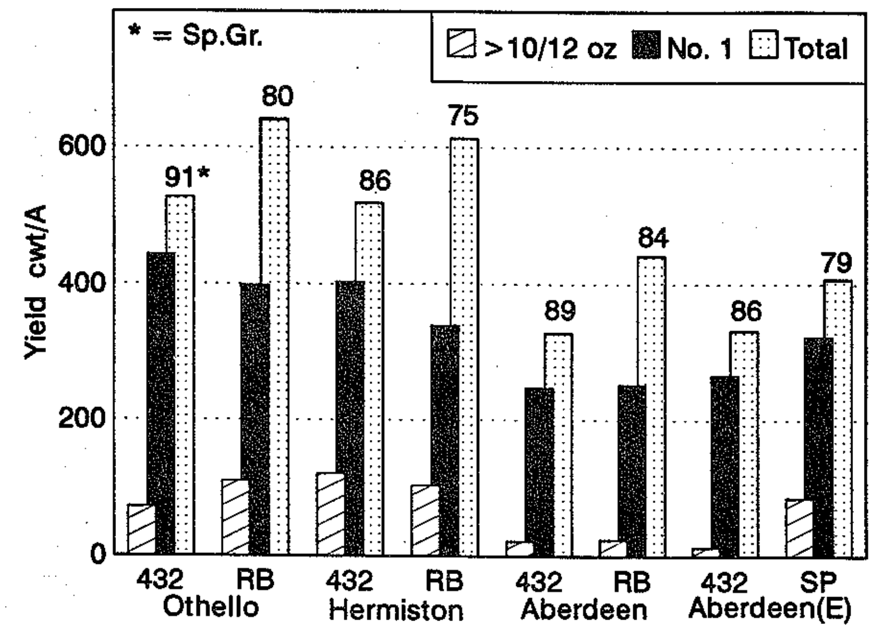


Figure 5. Average yields and specific gravities of multi-resistant Line A080432-1 compared to RB in 1991 and 1992 Tri-State trials.

a. Results in 1991, including early harvest comparison with Shepody (SP).



b. Results in 1992, including early harvest comparison with Shepody.

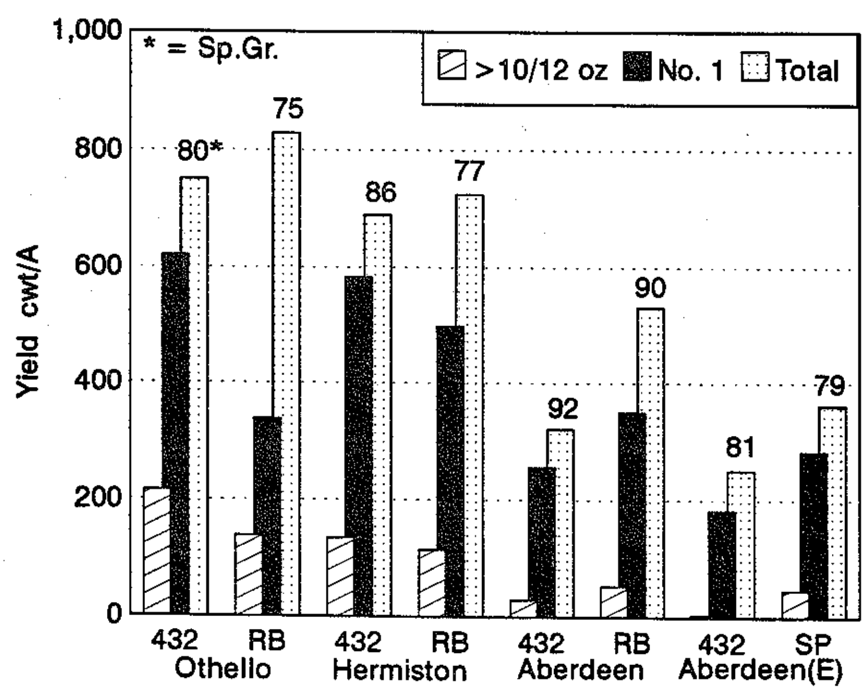


Figure 6. Average yields and specific gravities of four multi-resistant lines, A08478-1 (78), A084275-3(275), A81286-1(286), and A080432-1(432) compared to RB when grown in grower's fields at four locations in the Columbia Basin.

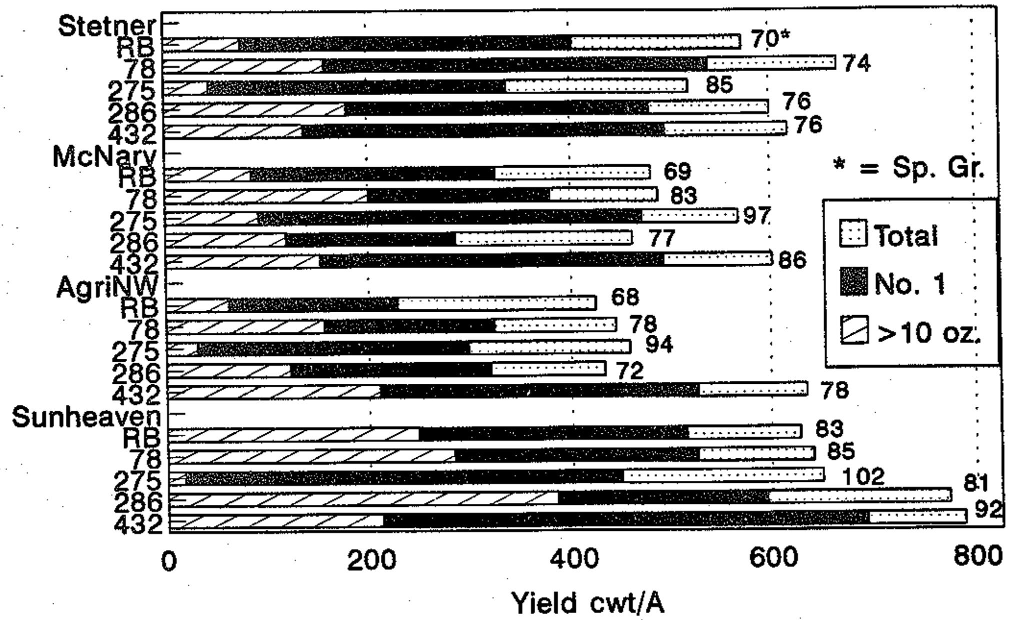


Figure 7. Average early dying resistance ratings of four multi-resistant lines compared to RB 1 mo and 2 wk before harvesting a trial conducted on Stetner Farms near George, Wa. in 1992.

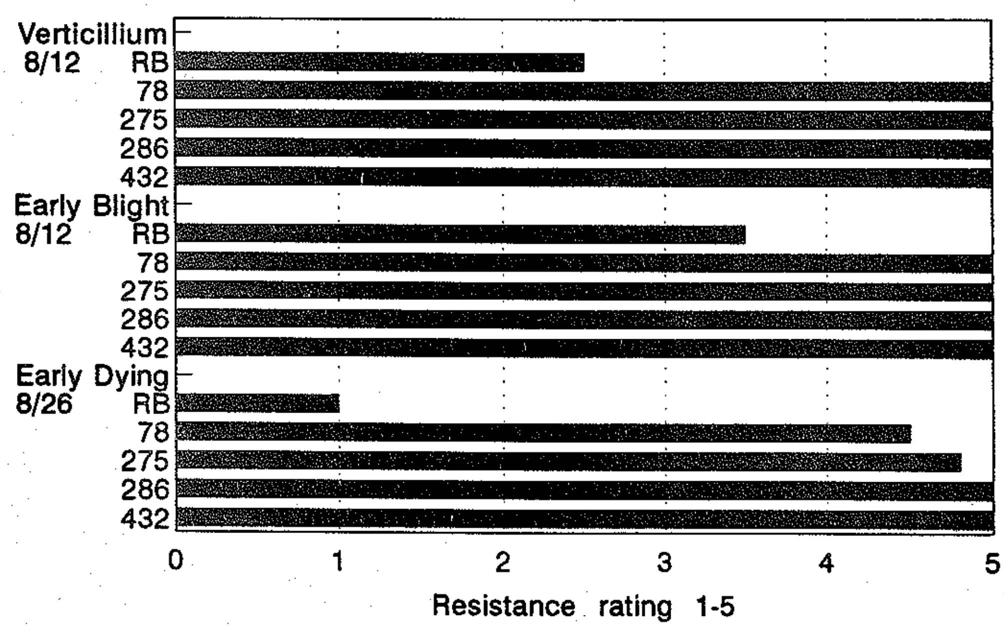


Figure 8. Average number of propagules of Verticillium dahliae and Colletotrichum coccodes in juice from RB and four multi-resistant lines 2 wks before harvesting a trial conducted on Stetner Farms near George, Wa. in 1992.

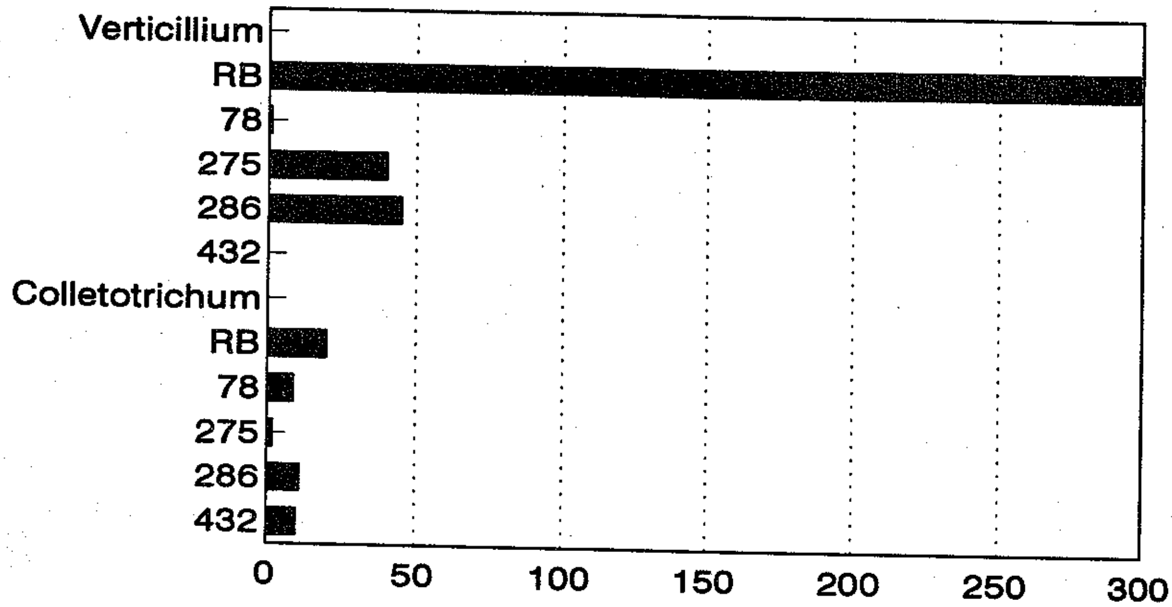


Figure 9. Yields and specific gravities of RB and four multi-resistant lines in Columbia Basin when allowed to grow full season (180 days) with minimal pesticides. Hermiston trial received severe virus and early dying disease exposure.

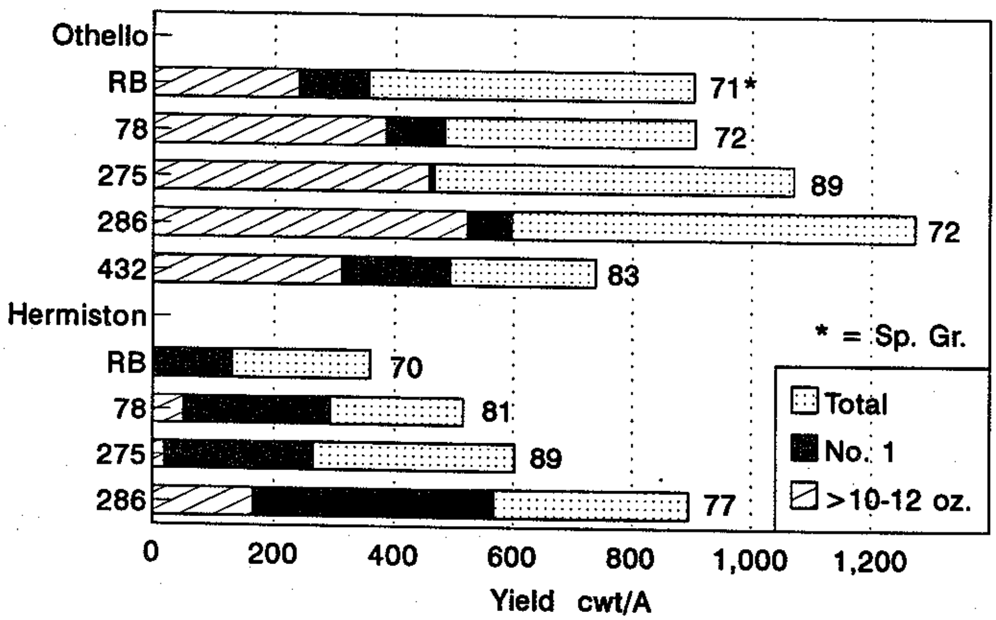


Figure 10. Yields and specific gravities of RB and four lines grown with minimal use of pesticides under severe exposures to virus and early dying diseases. Harvested Sept. or mid Oct., after value of resistance expressed.

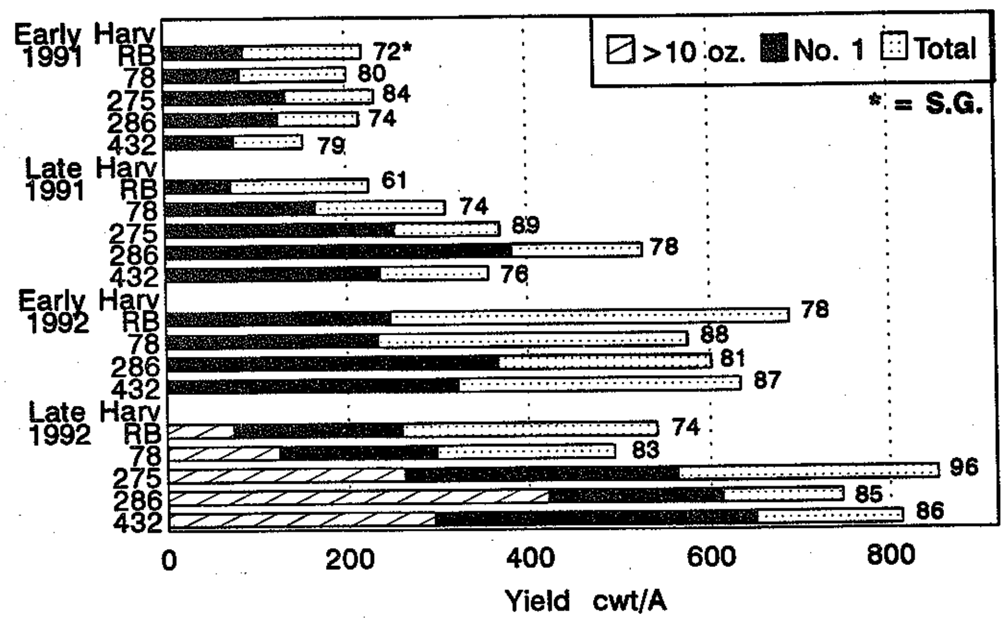


Figure 11. Average yields of RB and four multi-resistant lines when grown from virus infected seed with minimal pesticide applications.

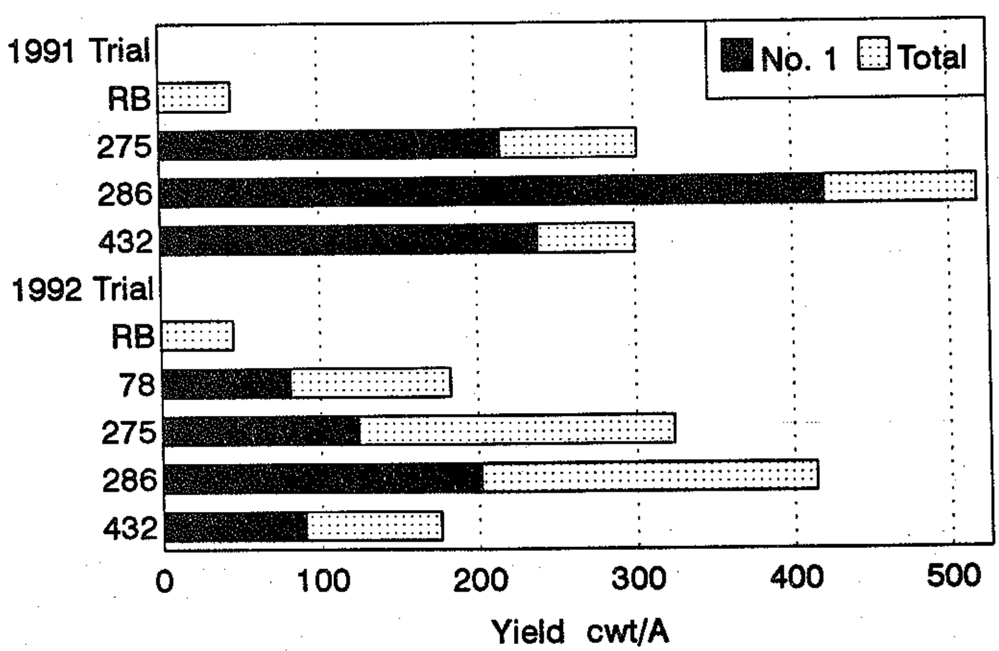


Figure 12. Average yields and specific gravities of RB and three multi-resistant lines in 1992 Wisconsin trials.

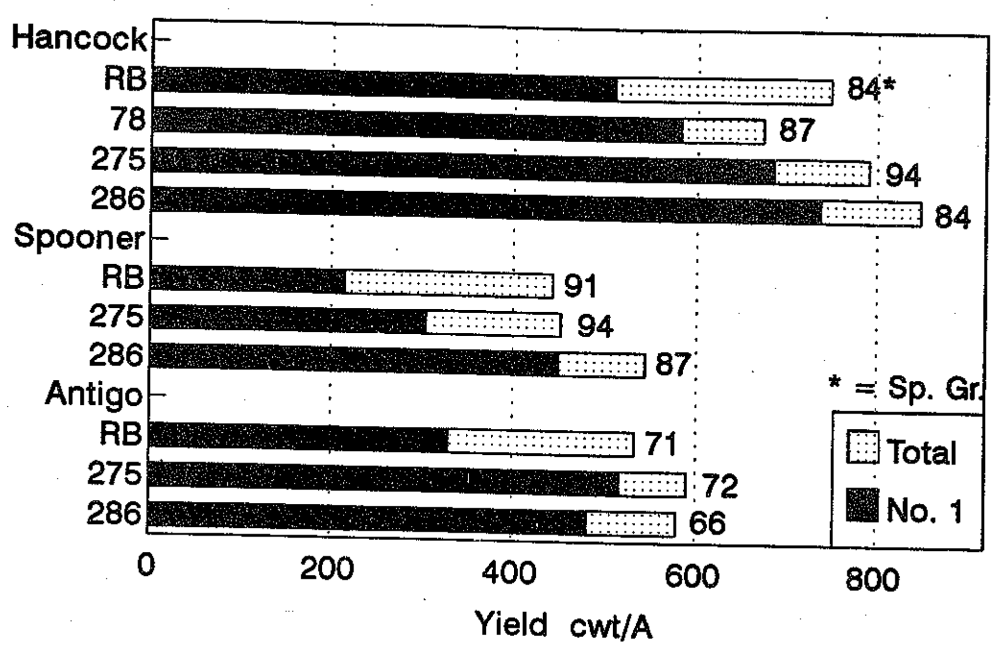
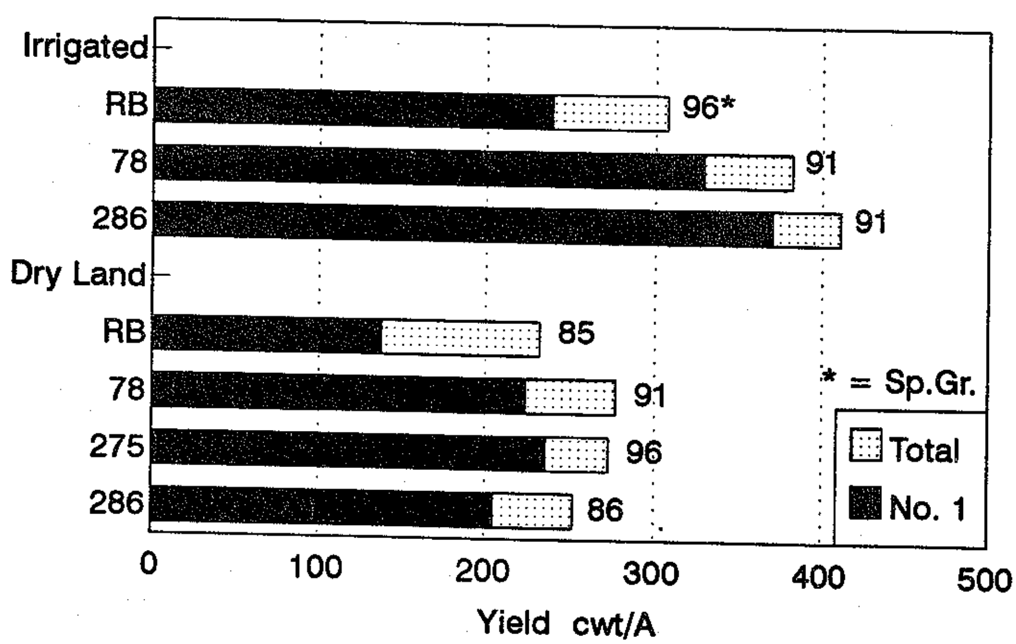


Figure 13. Average yields and specific gravities of RB and three multi-resistant lines in 1992 irrigated and non-irrigated trials in North Dakota.



The following paper was not available for publication in the 1993 Proceedings:

Washington Potato Industry Nitrogen Use - by: Dr. Bob Stevens, WSU, Prosser, Wa.