

## Response of Potato Cultivars to Infection by the Potato Spindle Tuber Viroid

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Research supported by the College of Agricultural and Life Sciences and the Graduate School, University of Wisconsin-Madison, and the Wisconsin Potato Industry Board.

We are grateful to Bonnie J. Zaleski for technical assistance and to Steven Vican for photographic assistance.

Accepted for publication 25 March 1980.

### ABSTRACT

PFANNENSTIEL, M. A., and S. A. SLACK. 1980. Response of potato cultivars to infection by the potato spindle tuber viroid. *Phytopathology* 70:922-926.

Symptom severity of potato spindle tuber disease was evaluated with respect to potato cultivar, inoculation method, and the strain of potato spindle tuber viroid (PSTV). Potatoes were inoculated by rubbing foliage with infectious Rutgers tomato sap (mechanical inoculation), by striking (switching) the potato foliage with an infected Rutgers tomato plant, or by mechanical inoculation followed 1 wk later by switching (combination inoculation). Switching inoculations and combination inoculations infected more plants and induced more severe symptoms than did mechanical inoculations. Fourteen potato cultivars were inoculated with a strain of PSTV that caused severe symptoms in Rutgers tomato (PSTV-S)

and symptom severity was assessed by measuring various foliage and tuber parameters. Disease severity caused by PSTV-S ranged from mild to severe, depending upon the potato cultivar. Three cultivars were tolerant. It is suggested that PSTV-tolerant cultivars may be important to PSTV perpetuation. Tolerant and susceptible potato cultivars were inoculated with PSTV-S and three strains of PSTV causing mild symptoms on Rutgers tomatoes (PSTV-M). In first-year infections, cultivars developed milder symptoms with the PSTV-M strains than with PSTV-S, and tolerant cultivars were less affected than were susceptible cultivars by PSTV-M.

The potato spindle tuber disease (PSTD) caused by potato spindle tuber viroid (PSTV) is primarily a problem in seed potato (*Solanum tuberosum* L.) certification programs, potato germplasm centers, and potato breeding programs. Diseased plants must be eliminated or isolated, but identification of infected plants is difficult because symptoms often are subtle or lacking. Symptoms of PSTD are influenced by potato cultivar (9) and PSTV strain (8), and are more severe at higher temperatures (3) and when successive generations of infected tubers are planted (9).

Werner (9) reported that symptoms in potato may not be visible in the season in which infection occurs, but symptoms increase in severity with successive generations of infection. Foliar symptoms include: stunting, uprightness, and small leaflets. Tubers produced by diseased plants are smaller, fewer in number, elongated, with numerous shallow eyes, and have abnormal skin color and texture. Although Werner (9) described these symptoms as typical, he also noted "varietal modification of symptoms;" ie, that symptoms of PSTD differed among potato cultivars.

Severe and mild strains of PSTV were differentiated by Fernow (2) on the basis of symptoms produced in tomato (*Lycopersicon esculentum* Mill 'Rutgers'); his classification is followed in this paper. The severe strain(s) of PSTV causes severe stunting, rugosity, and necrosis of Rutgers tomatoes, but the mild strain(s) causes a subtle stunting of plants which easily may be overlooked.

The effect of mild and severe strains on Saco potatoes was studied by Singh et al (8). In a field trial, three mild strains reduced yield by 17, 24, and 24%, while a severe strain reduced yield by 64%. From this study, it has been extrapolated that PSTV strains that cause mild or severe symptoms in Rutgers tomato also cause mild or severe symptoms in potato (1,8).

We present evidence in this report indicating that a strain of PSTV that induces severe symptoms in Rutgers tomato also causes a range of symptoms (mild to severe) in potato depending upon the cultivar inoculated. Further, data are presented which suggest that symptom severity varies in potato cultivars according to the PSTV strain used for inoculum and according to the method of inoculation. The significance of these data in relation to PSTV perpetuation in potatoes is discussed.

### MATERIALS AND METHODS

Field plots were maintained from 1976 through 1979 on the University of Wisconsin Hancock Experimental Farm. The following potato cultivars were tested: Katahdin, Kennebec, LaChipper, Monona, Norchip, Norgold Russet, Norland, Oneida, Ontario, Red LaSoda, Russet Burbank, Sebago, Superior, and Wischip. Tubers were hand-cut and allowed to suberize for 48 hr before planting. Each cultivar was planted in a single row with seed pieces spaced at 0.3 m in 1976 and 1977 and at 0.6 m in 1978 and 1979, and with treatments separated by 1-2 m. Rows were 0.9 m apart in 1976 and 1977 and 1.8 m apart in 1978 and 1979. Planting dates were 14 May 1976; 29 April 1977; 16 May 1978; and 26 April 1979.

Mild strain A (PSTV-MA) and a severe strain (PSTV-S) were obtained from E. D. Jones, Cornell University, Ithaca, and mild strains B and C (PSTV-MB and PSTV-MC, respectively) were supplied by W. J. Hooker, Michigan State University, East Lansing. Inoculum was increased in Rutgers tomatoes in a greenhouse. Potatoes and tomatoes were inoculated by rubbing corundum-dusted leaves with a tomato sap extract in neutral 0.1 M

TABLE 1. Effect of the method of potato spindle tuber viroid inoculation on tuber symptom development in potato

Cultivar	Number of plants with tuber symptoms <sup>a</sup>		
	Mechanical <sup>b</sup>	Switching <sup>c</sup>	Mechanical plus switching <sup>d</sup>
Katahdin	3	10	10
Kennebec	8	10	10
LaChipper	0	0	0
Norgold Russet	8	10	10
Russet Burbank	4	10	10

<sup>a</sup>Number of plants producing tubers with spindle tuber symptoms per 10 inoculated plants.

<sup>b</sup>Foliage inoculated by rubbing corundum-dusted potatoes with an infectious tomato extract in 0.1 M neutral phosphate buffer (1:5, w/v).

<sup>c</sup>Foliage inoculated by striking (switching) corundum-dusted potatoes five times with an infected Rutgers tomato plant.

<sup>d</sup>Potatoes inoculated by the mechanical method followed 1 wk later by switching.

potassium phosphate buffer (1:5, w/v) (mechanical inoculation). Potato plants also were inoculated by dusting with corundum and striking (switching) the potato foliage with an infected plant (5) (switching inoculations), or by mechanical inoculation plus switching inoculations 1 wk later (combination inoculation). Switching inoculations were made by vigorously striking potato foliage five times with a PSTV-infected Rutgers tomato plant. Inoculations were made 1–2 wk following emergence. Inoculated plants were designated as 1st-year infections (FYI), tubers harvested from FYI plants and planted the following year were called 2nd-year infections (SYI), and plants from tubers harvested from SYI plants were called 3rd-year infections (TYI).

Potato plants were observed for foliar symptoms three to five times between 1 June and 1 August. Plants were harvested separately in late August or early September and tuber symptoms recorded. Data were collected on the following tuber parameters: number and weight per plant, dimensions, eye number and depth, size distribution, and percentage with growth cracks.

## RESULTS

**Inoculation methods.** In the 1976 experiments, approximately 50% of all potato plants inoculated became infected with PSTV-S. The level of infection was determined by testing stem apices of greenhouse-grown SYI by polyacrylamide gel electrophoresis (6). In 1977, inoculation efficiency was only 5% for all potatoes inoculated. In 1976 and 1977, neither foliage nor tuber symptoms were observed in FYI plants. In 1978, however, when mechanical inoculation was supplemented by switching, virtually all potato

plants inoculated were infected and foliage and tuber symptoms were observed in FYI plants.

The change in inoculation procedure was suspected to be responsible for the increased inoculation efficiency and symptom severity, and a comparative test of inoculation procedures was designed. In this test, many plants did not show tuber symptoms after mechanical inoculation. All plants, except those of cultivar LaChipper, produced tubers with symptoms after switching inoculations or combination inoculations (Table 1). Norgold Russet and Russet Burbank expressed more severe symptoms when inoculated by the latter procedure.

**Foliar symptoms.** For FYI plants infected with PSTV-S, foliar symptoms were not observed during the 1976 or 1977 growing seasons,

TABLE 2. Stunting of potato cultivars infected for three generations with a severe strain of potato spindle tuber viroid<sup>a</sup>

Cultivar	Height (cm)		
	Healthy	Third-year infection	Reduction in height (%)
Katahdin	48.0 ± 2.0	31.5 ± 2.3	34
Kennebec	56.6 ± 2.0	38.6 ± 2.0	32
LaChipper	47.8 ± 2.3	39.4 ± 2.0	18
Russet Burbank	66.6 ± 1.0	24.9 ± 1.0	63
Superior	47.0 ± 0.8	25.7 ± 1.0	45

<sup>a</sup> Measurements which were taken on 7 July 1978 represent mean values for 10 plants ± their standard error.



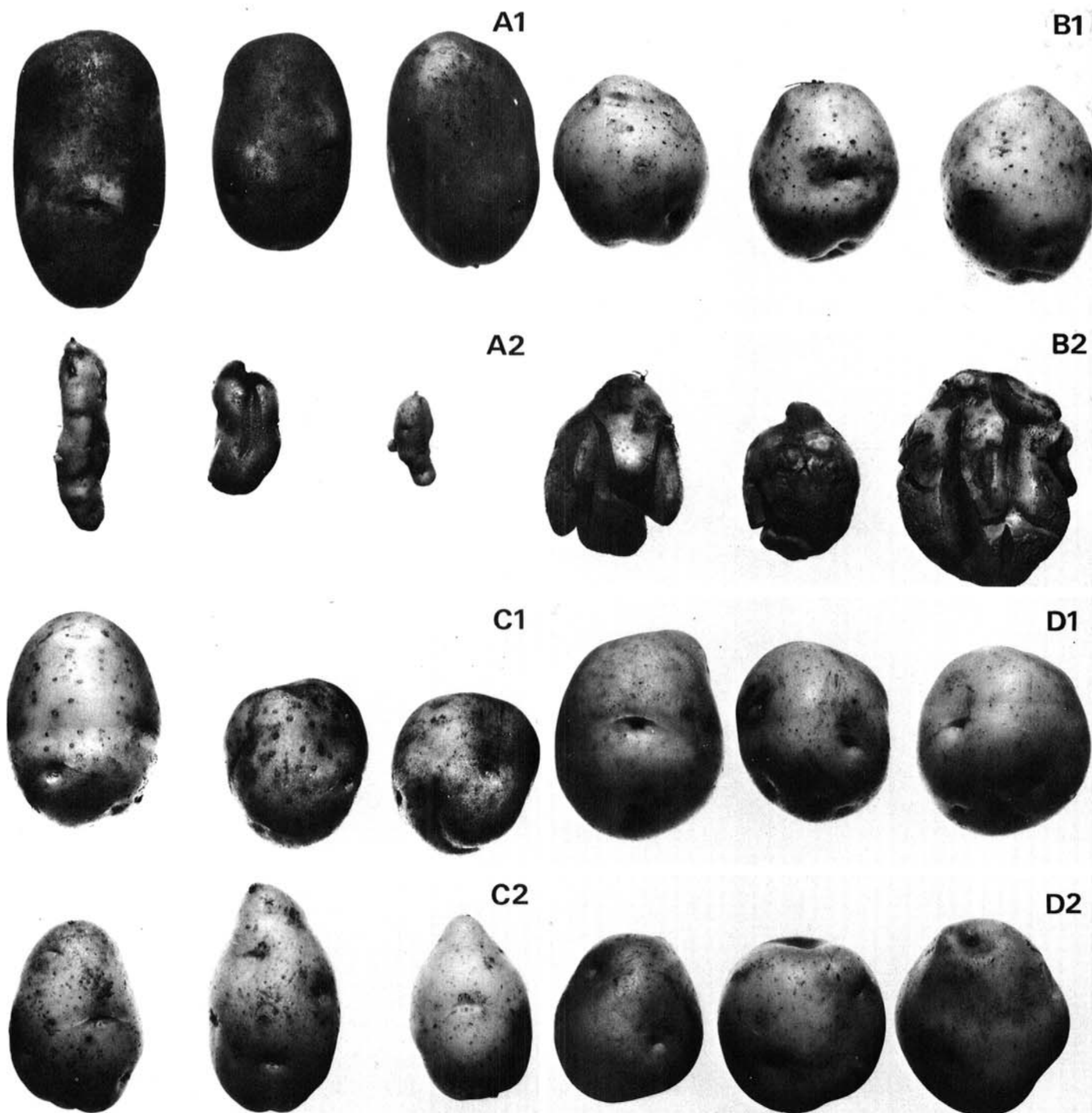
Fig. 1. Susceptible and tolerant foliar reactions to a severe strain of the potato spindle tuber viroid (PSTV) in Russet Burbank (A,B) and LaChipper (C,D) potatoes, respectively. Healthy (A,C) and third generation PSTV-infected (B,D) plants.

but were observed in 1978 and 1979. In the latter case, symptoms were not evident 4 wk post inoculation (PI), but were observed 7 wk PI. Stunting was not observed, but leaves developing approximately 7 wk PI were smaller and upright. Although almost all plants were infected, symptoms were not reliable for diagnosis because not all infected plants displayed foliar symptoms.

The SYI and TYI plants infected with PSTV-S showed the uprightness and stunting described by Werner (9). Symptom severity differed considerably among cultivars, however. The degree of stunting in TYI was compared for five cultivars which represented the range of observed symptoms (Table 2). The most and least severe TYI symptoms developed on Russet Burbank and LaChipper, respectively (Fig. 1).

**Tuber symptoms.** In 1976 and 1977, FYI tubers infected with PSTV-S were symptomless for all cultivars; but, in 1978 and 1979, FYI tubers exhibited PSTV symptoms. Symptoms were observed in SYI tubers for all cultivars except LaChipper, and for all cultivars in TYI tubers.

Decreased productivity of marketable tubers from PSTV-infected plants was measured by number and weight of tubers produced per plant, percentage of tubers with growth cracks (Table 3), and change in tuber size distribution. Infection increased, decreased, or did not alter significantly the number of tubers. Growth cracks were observed with high frequency in infected tubers, and occurred at a higher rate in SYI than FYI. The incidence of growth cracks usually decreased in TYI because these tubers



**Fig. 2.** Tubers of potato cultivars Norgold Russet (A), Norchip (B), Katahdin (C), and LaChipper (D) infected with a severe strain of the potato spindle tuber viroid (PSTV). Tubers from healthy (A1, B1, C1, and D1) and second-generation plants (A2, B2, C2, and D2) infected with PSTV.

were extremely small, and growth cracks occurred more frequently on larger tubers. Tuber weight was not decreased in seven of 14 cultivars in FYI, but only LaChipper was not affected in SYI. The decrease in tuber weight resulted primarily from a change in size distribution upon infection with PSTV; eg, 67% of LaChipper tubers were greater than 5.1 cm in diameter in both healthy and SYI tubers, while Norgold Russet had 62% of healthy tubers greater than 5.1 cm in diameter and 71% of SYI tubers were less than 2.5 cm in diameter. Norgold Russet was unique among cultivars tested, because large numbers of tiny tubers developed (>50 per plant) and aerial tubers at axillary nodes of stems were produced.

Tubers developed a variety of symptoms depending upon the cultivar infected (Fig. 2). In SYI, Norgold Russet became very spindly upon infection with PSTV and productivity was drastically reduced; although Norchip tubers did not decrease in size, they developed extreme growth cracks; Katahdin tubers exhibited mild symptoms; and LaChipper tubers were symptomless.

Other symptoms attributed to PSTV are spindly tubers, a decrease in eye depth, and an increase in the number of eyes per tuber (9). For FYI tubers, these parameters did not differ from healthy tubers. Differences were obtained in SYI and TYI in some cultivars, but the values obtained did not reflect disease severity or definite trends, and these data are not presented.

**Viroid strains.** In 1979, Katahdin, Kennebec, LaChipper, Norgold Russet, and Russet Burbank were inoculated with three isolates of PSTV-M and with PSTV-S by the combination method. Foliar symptoms appeared to be similar for all strains in FYI. In Katahdin, Kennebec, and LaChipper infected with PSTV-S, tuber weight was unaffected or increased, but, in Norgold Russet and Russet Burbank infected with PSTV-S, tuber weight decreased (Table 4) and tuber symptoms were more pronounced. In contrast, infection with PSTV-M did not reduce tuber weight in any cultivar (Table 4), but tuber symptoms were more pronounced for Norgold Russet and Russet Burbank.

## DISCUSSION

The switching method of inoculation reported by Merriam and Bonde (5) was more efficient than was mechanical inoculation for infecting potato plants with PSTV. In this study, PSTV-infected tomato instead of potato plants were used for switching inoculations. When the switching method was used, inoculation efficiency approached 100% compared to 50% or less for mechanically inoculated potato plants. The reason for the low efficiency of mechanical inoculations in the field is unknown. In our experience, mechanical inoculation of Rutgers tomatoes and potato seedlings in the greenhouse approaches 100% efficiency. In addition, experiments with PSTV-S demonstrated that the combination inoculation method increased symptom severity the year of inoculation, and SYI plants were equivalent in disease severity to TYI obtained by using the mechanical method of inoculation alone.

Disease severity varied widely among cultivars. To quantify disease severity, many tuber and foliar parameters were evaluated. Tuber weight best assessed disease severity. LaChipper, Kennebec, and Katahdin were least affected by PSTV-S infection, while the other 11 cultivars tested developed very severe symptoms. Symptoms ranged from mild to severe depending upon the cultivar, although all cultivars were inoculated with the same strain of PSTV. Cultivars LaChipper, Katahdin, and Kennebec may be classified as tolerant based on Matthews' (4) definition of tolerance (ie, viroid multiplication and spread occurring throughout the plant but symptom expression is mild or negligible). The remaining 11 cultivars may be classified as susceptible.

It has been suggested previously that PSTV is perpetuated at low incidence in North American potato-growing areas because mild strains of the pathogen cannot be detected easily during visual examination of stocks (2,8). Our studies support this assessment as all potato cultivars tested developed mild symptoms when inoculated with three PSTV-M strains. Our demonstration that cultivars exist which are tolerant to severe as well as to mild PSTV

TABLE 3. Effects of a severe strain of potato spindle tuber viroid (PSTV) on tuber development in potato<sup>a</sup>

Cultivar	Decrease in tubers produced per plant (%)			Increase in tubers with growth cracks (%)			Decreases in tuber weight per plant (%)		
	FYI	SYI	TYI	FYI	SYI	TYI	FYI	SYI	TYI
Katahdin	24	39	ns <sup>b</sup>	12	31	10	ns	44	58
Kennebec	17	23	-40 <sup>c</sup>	39	35	44	ns	24	24
LaChipper	ns	ns	ns	5	ns	5	ns	ns	21
Monona	ns	43	36	15	22	12	26	64	91
Norchip	-38	20	ns	30	83	50	23	ns	81
Norgold Russet	-67	-39	ns	56	44	66	46	88	92
Norland	-18	67	49	8	59	39	ns	81	91
Oneida	-26	68	53	33	62	10	16	87	96
Ontario	ns	82	80	18	38	25	19	82	97
Red LaSoda	-40	33	44	53	45	53	ns	48	85
Russet Burbank	-33	56	ns	56	56	25	13	69	90
Sebago	ns	63	40	52	32	41	32	47	84
Superior	ns	45	32	11	41	13	ns	62	88
Wischip	-22	67	52	16	30	53	ns	85	89

<sup>a</sup>Tubers produced by inoculated plants are 1st-yr infections (FYI), replanted tubers produce 2nd-year infections (SYI), and tubers replanted again produce 3rd-yr infections (TYI). FYI and TYI data is from 1978, and SYI data is from 1977. Data collected on 10 - 20 PSTV-infected and healthy plants of each cultivar in the same field plot. FYI plants were inoculated by the combination method (mechanical leaf rubbing with sap from infected Rutgers tomato followed 1 wk later by striking the same corundum-dusted plants five times with an infected Rutgers tomato plant), and SYI and TYI plants resulted from FYI inoculated only by the mechanical method.

<sup>b</sup>Values reported represent significant differences ( $P = 0.05$ ) from healthy controls according to Student's *t*-test; ns = not significant.

<sup>c</sup>Negative sign indicates an increase in number of tubers per plant compared to healthy control.

TABLE 4. Effect of potato spindle tuber viroid (PSTV) strains on potato tuber weight in 1979

Cultivar	Tuber weight per plant <sup>a</sup> (kg)				
	Healthy	PSTV strain			
		Severe	Mild-A	Mild-B	Mild-C
Katahdin	2.6 ± 0.3	3.3 ± 0.5	2.8 ± 0.3	3.3 ± 0.5	2.6 ± 0.5
Kennebec	3.5 ± 0.3	4.8 ± 0.3	4.2 ± 0.3	4.3 ± 0.4	4.0 ± 0.3
LaChipper	3.9 ± 0.3	4.2 ± 0.5	4.2 ± 0.2	4.1 ± 0.4	4.3 ± 0.3
Norgold Russet	3.3 ± 0.4	2.4 ± 0.2	3.4 ± 0.3	3.3 ± 0.4	3.0 ± 0.3
Russet Burbank	3.4 ± 0.3	2.4 ± 0.4	3.8 ± 0.3	3.9 ± 0.3	3.8 ± 0.2

<sup>a</sup>Averages were based on 10 plants per treatment and are followed by ± their standard error. Foliage was inoculated by combination method (mechanical leaf rubbing with juice of infected Rutgers tomato plant on 30 May and striking the corundum-dusted potato foliage five times with an infected Rutgers tomato plant on 6 June 1979).

strains, however, suggests that PSTV-tolerant cultivars also are important to PSTV survival.

This study reaffirms the need for additional assay procedures to supplement visual detection of PSTV in valuable germplasm and seed stocks. A polyacrylamide gel electrophoresis assay suitable for screening field-grown potatoes was developed to address this problem and is reported in an associated study (7).

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