Effects of Wheat Spindle Streak Mosaic Virus on Winter Wheat

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ABSTRACT

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Infection by the wheat spindle streak mosaic virus (WSSMV) significantly reduced vigor of cultivars Abe and Redcoat in 1977-1978 in Pennsylvania. In both years, WSSMV infection occurred only on field plots that were inoculated with virus-bearing soil and planted by late September or early October. No leaf symptoms developed in the field, but plant growth and yield were significantly reduced at most locations on plots receiving infectious soil inoculum, compared with control plots receiving steam-treated soil inoculum. The 2-yr average reductions in grain yield, straw yield, and tillers were 7, 8, and 9%, respectively, on Hart and 24, 18, and 22% on Redcoat. Plant height reduction was significant on Abe and Redcoat but not significant on Hart, Blueboy, and Ruler. The percent of seed retained on a 2.8-mm slotted screen was significantly reduced on all cultivars except Hart. Based on field data and leaf symptom severity ratings, Hart was least affected, Blueboy and Ruler were moderately affected, and Abe and Redcoat were most affected by WSSMV. Steam-air soil treatment at 74 C for 30 min controlled the infectivity of the virus. Late planting in the fall of 1977 may have avoided WSSMV of wheat, but plant growth was severely reduced and grain losses were as high as 64%. Resistant or tolerant cultivars offer the best control.

Additional key words: soil fumigation, soil steam-air treatment, soilborne virus, *Triticum aestivum*, wheat yield loss

Wheat spindle streak mosaic virus (WSSMV) has caused substantial losses of winter wheat in Pennsylvania and in the eastern soft wheat region. It was first recognized in southern Ontario, Canada, and described by Slykhuis (7,8) and Slykhuis and Polak (13). Since then the disease has been reported in Michigan (16), Indiana (3), Kentucky (17), Maryland, New York, and southern France (11) and in India (1).

Wheat spindle streak mosaic is caused by a soilborne virus that is a flexuous, rod-shaped particle frequently exceeding 2,000 nm in length (2,3,11,14). Natural transmission of WSSMV is through infectious soil, and the zoosporic fungus *Polymyxa graminis* Led. is a recently reported vector (15). WSSMV has a very narrow host range. Only common wheat (*Triticum aestivum* L. em Thell.) and durum wheat (*T. turgidum* L.) are known hosts (8,11). WSSMV can survive in soil for 6 yr, even in the absence of wheat, and the amount of inoculum in soil increases with the frequency of wheat cropping on infected fields (11).

Temperature is the major climatic factor affecting disease development (9,10). When the soil temperature is near 15 C, wheat sown in infectious soil in the fall becomes infected after emergence (approximately 2 wk after seeding). When host growth resumes in the spring, leaf symptoms develop if soil temperature is in the cool, "critical range" of 5–13 C. The optimum temperature is about 10 C. If higher temperatures occur early in the spring, infected plants fail to develop "mosaic" symptoms, leaving little visual evidence of the disease.

Several workers (3–5,8,15,17) have found apparent resistance or tolerance to WSSMV in wheat. In particular, the cultivar Hart is tolerant to WSSMV (6).

Slykhuis (8) reported that methyl bromide suppressed WSSMV completely. He also found that the virus was made noninfective by heating the soil for 30 min in a water bath at 52 C or higher.

The objectives of this experiment were to describe cultivar reaction to WSSMV in the field in relation to planting date, plant growth and vigor, and environment in Pennsylvania; evaluate the tolerance of five wheat cultivars to WSSMV; and develop a measure of disease loss in wheat.

MATERIALS AND METHODS

Treatments were arranged as a complete 5 × 2 factorial experiment with cultivars and soil treatments as the main effects. Five winter wheat cultivars, *Triticum aestivum* L. em. Thell. 'Hart,' 'Blueboy,' 'Ruler,' 'Abe,' and 'Redcoat,' were grown in randomized complete block designs with four replications at five locations throughout Pennsylvania in the fall of 1976 and at four locations in 1977. These cultivars were thought to have varying degrees of tolerance to WSSMV, with Hart being the most tolerant and Redcoat the least tolerant. Each wheat cultivar occurred twice in each experimental block: One plot received infectious soil inoculum and the control plot received steam-air treated soil inoculum. Each field plot was 30 × 305 cm. Single rows of Maury barley (*Hordeum vulgare* L.) were planted alternately with the wheat plots and served as border rows.

Soil inoculum was obtained from Oval, PA. The surface 10 cm of top soil was removed from a field where WSSMV had been severe for several crop seasons. This soil was shredded and the half to be used as noninfectious was treated by applying steam air at 74 C for 30 min.

In the fall of 1977, both early and late planting dates were used. In addition, a soil fumigation experiment, with methyl

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bromide as the fumigant, was conducted in 1977 at Rock Springs. This experiment shared a common 5 × 2 factorial arrangement in a randomized complete block design. Specific planting dates and locations are listed in Table 1.

Experimental sites were selected where wheat had not been grown within the last 8 or more years. The sites were distributed in the state to represent different environmental conditions and to increase the likelihood of favorable conditions for WSSMV development at one or more locations.

Twelve grams of seed were sown about 3.8 cm deep in each row, covered with either a 1-cm layer of infectious soil or a layer of steam-treated soil, and finally covered with an additional layer of field soil. No soil treatment was used for the barley border rows. A spring topdressing of 44.8 kg N/ha as ammonium nitrate was applied to all plots.

In the fumigation experiment at Rock Springs, 1,362 g of methyl bromide was applied to each 28-m^2 experimental block under a plastic tarpaulin sealed at the edges by soil. The plastic was removed after 5 days, and the fumigated soil was exposed to air for 3 days before planting.

The general appearance of plots in the early spring or in the growth chamber was rated on a scale of 1 to 5, with 1 representing vigorously growing, deep green plants and 5 representing weak, pale green plants. Ten plants were removed from every plot in early spring, replanted in steam-air treated soil, and kept in a growth chamber controlled at a mean temperature of 10 C for 38 days at 115 $\mu E\ m^{-2}\ sec^{-1}$ of light for 12 hr per day.

At flowering the wheat heads per 1 m of row were counted and expressed as tillers per square meter. At ripening the height of representative main tillers was measured in centimeters. When the plants were fully ripe, individual plots were trimmed to a length of 2.4 m and harvested with a hand sickle. The samples were bundled in paper bags. The bundles were stored for at least 4 days in a room at 40% relative humidity and 11 C in an attempt to equalize the moisture content of the straw and grain among samples. A 100-g grain sample from each plot was placed on a vibrating set of screens (malt barley fractionator) for 15 sec, and the percentages of grain retained on 2.8, 2.4, and 2.0 mm slotted screens were determined by weighing these fractions.

RESULTS AND DISCUSSION

Field trials, 1976-1977. Infection by WSSMV caused reduction of plant vigor of the most susceptible cultivars at the Jersey Shore and Catawissa locations. The difference in vigor between plants grown with steam-air treated inoculum and infectious inoculum field plots was significant ($P = 0.01$) and consistent for the two locations for Redcoat and Abe. The vigor of Hart, Blueboy, and Ruler cultivars did not differ significantly. At these two locations, the infectious inoculum significantly affected tillers, grain yield, straw yield, plant height, and percent of grains retained on a 2.8-mm slotted screen (Table 2).

No WSSMV symptoms were seen in the field at either Jersey Shore or Catawissa but the infection of plants from both locations was demonstrated in the growth chamber. Only plants removed from the infectious plots at those locations developed typical WSSMV leaf symptoms. Five weeks after replanting, WSSMV severity was rated 4 on Redcoat and Abe, 3 on Ruler, 2 on Blueboy, and 1 on Hart. Our interpretation of results from the growth chamber study is that the use of infectious soil inoculum transmitted WSSMV. Also the use of steam-air treatment of soil at 74 C for 30 min eliminated the infectivity of the soil inoculum containing WSSMV and its vector. Only a 1-cm layer of infectious soil was needed to infect plants in field plots planted before 10 October.

Considering all characteristics, it appeared that Hart was least affected by WSSMV, Redcoat and Abe were most severely affected, and Blueboy and Ruler were moderately affected (Table 2). There was no significant reduction in percentage of large seeds on Hart. There was no significant height reduction of Hart, Blueboy, and Ruler, but plant height of Redcoat and Abe was significantly reduced by about 4 and 5%, respectively. For the two locations, the average reductions in grain yield, straw yield, and tillers were about 5, 8, and 9%, respectively, on Hart and about 23, 19, and 23% on Redcoat due to WSSMV.

No WSSMV symptoms developed on the plants that were removed from the field and at the Rock Springs, Rochester Mills, and Landisville locations grown in the growth chamber for 5 wk. Also, there

Table 1. Location and planting date of WSSMV experiments in Pennsylvania

	Month/Day		
		1977	
Locations	1976	Early	Late
Rock Springs, Centre County	10/13	10/13	11/01
Jersey Shore, Lycoming County	10/05	10/14	11/01
Catawissa, Columbia County	10/06	10/07	11/01
Landisville, Lancaster County	10/14	10/04	10/29
Rochester Mills, Indiana County	10/16	...	...
Methyl bromide soil fumigation experiment at Rock Springs	...	09/29	...

Table 2. Performance of five wheat cultivars inoculated with wheat spindle streak virus and grown at Jersey Shore and Catawissa, PA, 1977

	Tillers (no./m^2)			Grain yield (kg/ha)			Straw yield (ton/ha)			Plant height (cm)			Seed on 2.8-mm screen (%)		
Cultivar	C[a]	I[b]	D[c]	C	I	D	C	I	D	C	I	D	C	I	D
Jersey Shore															
Hart	440	401	39*[d]	4,730	4,489	241*	5.67	5.28	0.39*	88	87	1	52	52	0
Abe	487	393	94**[e]	4,716	4,066	650**	5.40	4.40	1.00**	86	82	4*	73	71	2*
Redcoat	467	379	88**	4,375	3,691	684**	7.06	5.85	1.21**	105	101	4*	34	31	3**
Blueboy	510	444	66**	6,110	5,621	489**	6.67	5.71	0.96**	90	89	1	61	59	2*
Ruler	490	414	76**	5,929	5,420	509**	6.74	5.80	0.94**	92	90	2	60	58	2*
Catawissa															
Hart	427	387	40*	4,046	3,812	234*	4.23	3.87	0.36*	74	73	1	30	29	1
Abe	316	213	103**	2,700	2,023	677**	3.70	2.64	1.06**	68	63	5**	52	46	6**
Redcoat	350	253	97**	3,048	2,358	690**	4.40	3.40	1.00**	81	77	4**	14	10	4*
Blueboy	430	372	58**	4,207	3,731	476**	5.71	4.73	0.98**	77	75	2	19	16	3
Ruler	390	328	62**	4,261	3,765	497**	5.66	5.03	0.63**	75	73	2	37	33	4*

[a] C = control, steam-air treated soil inoculum, mean of four replicates.
[b] I = infectious soil inoculum, mean of four replicates.
[c] D = difference between control and inoculated plots.
[d] * = Significantly different from control at $P = 0.05$.
[e] ** = Significantly different from control at $P = 0.01$.

Table 3. Performance of five wheat cultivars grown in methyl bromide fumigated soil and inoculated with wheat spindle streak virus at Rock Springs, PA, 1978

Cultivar	Tillers (no./m²)			Grain yield (kg/ha)			Straw yield (ton/ha)			Plant height (cm)			Seed on 2.8-mm screen (%)		
	C[a]	I[b]	D[c]	C	I	D	C	I	D	C	I	D	C	I	D
Hart	602	546	56*[d]	4,598	4,278	320*	7.80	7.33	0.47*	97	97	0	40	39	1
Abe	821	654	167**[e]	5,691	4,858	833**	7.54	6.72	0.82**	98	93	5**	83	75	8**
Redcoat	860	695	165**	5,933	4,981	952**	7.71	6.59	1.12**	101	94	7**	85	80	5*
Blueboy	609	529	80**	5,609	5,004	605**	9.27	8.22	1.05**	103	101	2	55	50	5*
Ruler	685	595	90**	5,800	5,063	737**	9.29	8.18	1.11**	101	99	2	52	47	5*

[a] C = control, steam-air treated soil inoculum, mean of four replicates.
[b] I = infectious soil inoculum, mean of four replicate.
[c] D = difference between control and inoculated plots.
[d] * = Significantly different from control at $P = 0.05$.
[e] ** = Significantly different from control at $P = 0.01$.

Table 4. Performance of five wheat cultivars inoculated with wheat spindle streak virus and planted early at Landisville and Catawissa, PA, 1978

Cultivar	Tillers (no./m²)			Grain yield (kg/ha)			Straw yield (ton/ha)			Plant height (cm)			Seed on 2.8-mm screen (%)		
	C[a]	I[b]	D[c]	C	I	D	C	I	D	C	I	D	C	I	D
Landisville															
Hart	614	567	47*[d]	3,365	3,105	260*	5.83	5.40	0.43*	98	97	1	58	58	0
Abe	607	492	115**[e]	2,773	2,063	710**	4.87	3.92	0.95**	95	90	5**	84	81	3*
Redcoat	572	450	122**	2,723	2,063	660**	4.51	3.53	0.98**	97	93	4**	82	77	5**
Blueboy	598	538	60**	3,556	3,110	446**	6.16	5.57	0.59**	101	100	1	64	60	4*
Ruler	619	527	92**	2,850	2,463	387**	5.83	5.29	0.54**	99	98	1	62	58	4*
Catawissa															
Hart	491	440	51*	3,488	2,993	495*	4.57	4.12	0.45*	84	84	0	41	40	1
Abe	679	563	116**	4,940	3,756	1,183**	5.81	4.10	1.71**	89	85	4**	79	74	5**
Redcoat	671	533	138**	4,681	3,019	1,662**	5.24	4.53	0.71**	87	83	4**	76	72	4**
Blueboy	532	442	90**	5,081	4,157	924**	7.73	5.97	1.76**	96	95	1	50	47	3**
Ruler	572	501	71**	5,195	4,403	792**	6.59	5.62	0.97**	90	89	1	64	60	4**

[a] C = control, steam-air treated inoculum, means of four replicates.
[b] I = infectious soil inoculum, means of four replicates.
[c] D = different between control and inoculated plots.
[d] * = Significantly different from control at $P = 0.05$.
[e] ** = Significantly different from control at $P = 0.01$.

were no significant differences in the field between the control and inoculated plots for any cultivar. Because the diseased plants at Jersey Shore and Catawissa were planted earlier, the later planted plots may have escaped transmission of the virus, or development of the disease was not sufficient to be detected. Slykhius and Barr (12) found that the optimum transmission of the virus was at 15 C and very little transmission occurred at 10 C. Soil temperatures at Rock Springs fell to 7 C at 5-cm under bare soil 10 days after planting.

Field trials, 1977-1978. Fumigation with methyl bromide may have made soil noninfective for WSSMV, or the plot site may have been free of WSSMV. Weeds were completely controlled in this trial, and it is possible that soilborne insects and pathogens were also controlled. Thus the differences attributed to inoculum may be less confounded by other factors in this trial. Possibly the effect of the inoculum in all the trials may be caused by something other than WSSMV, but WSSMV symptoms developed in plants from the inoculated plots only. The differences between the control and infectious plots in tiller number, grain and straw yield, plant height, and percent of seed retained on 2.8-mm screen were highly significant (Table 3). Similar effects of the virus also were found after early seeding at Landisville and Catawissa (Table 4).

Table 5. Grain yields from early and late planted plots at Landisville and Catawissa, 1978

Cultivar	Landisville (kg/ha)			Catawissa (kg/ha)		
	Early[a]	Late[b]	D[c]	Early	Late	D
Hart	3,365	2,130	1,235**[d]	3,488	2,307	1,181**
Abe	2,773	1,097	1,676**	4,940	1,663	3,277**
Redcoat	2,723	1,109	1,614**	4,681	1,716	2,965**
Blueboy	3,556	2,055	1,501**	5,081	1,897	3,184**
Ruler	2,850	1,750	1,100**	5,195	2,067	3,128**

[a] Control, early planted, no infectious inoculum, mean of four replicates.
[b] Late planted, no infectious inoculum, mean of four replicates.
[c] Difference between control and late planted plots.
[d] ** = Significantly different from the early planted plots at $P = 0.01$.

Hart was consistently least affected by WSSMV (Tables 3 and 4), while Blueboy and Ruler were moderately affected and Abe and Redcoat most affected. At the Rock Springs, Landisville, and Catawissa locations, the average reductions in grain yield, straw yield, and tiller number were 9, 7, and 9%, respectively, for Hart and 25, 16, and 20% for Redcoat.

No plants from the late planted plots developed WSSMV symptoms after 5 wk in the growth chamber. Also, there were no significant effects in the field for the inoculum treatment on the late planted plots at all five locations. The plants may have evaded the effects of the disease that were observed in the early planted plots (Table 4). A measure of performance caused by late planting is given in Table 5, using the control plot data as listed in Table 4 as the early planted control, compared with the control plot data from the late planted plots. Yield losses for late planting ranged from 25 to 64% and were greater than the losses after inoculation with WSSMV in the early plantings.

Apparently late planting is not always a satisfactory method to evade losses from WSSMV.

On the basis of average control plot data for grain yield from Tables 2–4, the cultivar rank for yield is Blueboy, Ruler, Abe, Redcoat, and Hart. In the inoculated plots, the cultivars ranked Ruler, Blueboy, Hart, Abe, and Redcoat. In terms of loss of least yield, the cultivars ranked Hart, Ruler, Blueboy, Abe, and Redcoat, at 310, 584, 588, 810, and 929 kg/ha, respectively. These differences were obtained in a 2-yr period in plots planted early and inoculated using a method that produced consistent responses. We suggest that cultivars show three levels of tolerance to WSSMV: Hart was most tolerant; Ruler and Blueboy were intermediately tolerant; and Abe and Redcoat were least tolerant and were considered susceptible. A reasonable goal should be improvement of cultivar performance by breeding WSSMV tolerance into lines of high potential yield.

Late planting of wheat (late October or early November in Pennsylvania) may avoid fall infection by WSSMV, but this may be too late for satisfactory winter survival and vigorous spring recovery of wheat. Thus, resistant or tolerant cultivars are needed, especially under continuous or relatively short rotation wheat cropping, to prevent significant losses due to WSSMV.

LITERATURE CITED

1. AHLAWAT, Y. S., A. MAJUMDAR, and V. V. CHENULU. 1976. First record of wheat spindle streak mosaic in India. Plant Dis. Rep. 60:782-783.
2. HOOPER, G. R., and M. V. WIESE. 1972. Cytoplasmic inclusions in wheat affected by wheat spindle streak mosaic. Virology 47: 664-672.
3. JACKSON, A. O., C. E. BRACKER, D. M. HUBER, D. H. SCOTT, and G. SHANER. 1975. The occurrence and transmission of a disease in Indiana with properties of wheat spindle streak mosaic virus. Plant Dis. Rep. 59:790-794.
4. JACKSON, A. O., C. E. BRACKER, and G. SHANER. 1976. Mechanical transmission, varietal reactions and electron microscopy of a disease in Indiana with properties of wheat spindle streak mosaic. Plant Dis. Rep. 60:202-206.
5. MISKIN, K. E. 1975. Registration of W504 wheat. Crop Sci. 15:737-738.
6. SECHLER, D., J. M. POEHLMAN, and R. P. PFEIFER. 1977. Registration of Hart wheat. Crop Sci. 17:980.
7. SLYKHUIS, J. T. 1960. Evidence of a soil-borne mosaic of wheat in Ontario. Can. Plant Dis. Surv. 40:43.
8. SLYKHUIS, J. T. 1970. Factors determining the development of wheat spindle streak mosaic caused by a soil-borne virus in Ontario. Phytopathology 60:310-331.
9. SLYKHUIS, J. T. 1974. Differentiation of transmission and incubation temperatures for wheat spindle streak mosaic virus. Phytopathology 64:554-557.
10. SLYKHUIS, J. T. 1975. Seasonal transmission of wheat spindle streak mosaic virus. Phytopathology 65:1133-1136.
11. SLYKHUIS, J. T. 1976. Wheat spindle streak mosaic virus. No. 167 in: Descriptions of plant viruses. Commonw. Mycol. Inst. Assoc. Appl. Biol., Kew, Surrey, England. 4 pp.
12. SLYKHUIS, J. T., and D. J. S. BARR. 1978. Confirmation of *Polymyxa graminis* as a vector of wheat spindle streak mosaic virus. Phytopathology 68:639-643.
13. SLYKHUIS, J. T., and Z. POLAK. 1969. Verification of wheat spindle streak mosaic virus as a cause of mosaic of wheat in Ontario. Can. Plant Dis. Surv. 49:108-111.
14. WIESE, M. V., and G. R. HOOPER. 1971. Soil transmission and electron microscopy of wheat spindle streak mosaic. Phytopathology 61: 331-332.
15. WIESE, M. V., A. RAVENSCROFT, and E. H. EVERSON. 1974. Incidence of wheat spindle streak mosaic among ten wheat cultivars and its effect on yield. Plant Dis. Rep. 58:522-525.
16. WIESE, M. V., E. E. SAARI, J. CLAYTON, and A. H. ELLINGBOE. 1970. Occurrence of wheat streak mosaic and a new varigation disorder, wheat spindle streak mosaic, in Michigan wheat. Plant Dis. Rep. 54:635-637.
17. WILLIAMS, A. S., T. P. PIRONE, J. T. SLYKHUIS, and C. R. TUTT. 1975. Wheat spindle streak mosaic virus in Kentucky. Plant Dis. Rep. 59:888-889.