Effects of Planting Date and Inoculation Date on Severity of Wheat Streak Mosaic in Hard Red Winter Wheat Cultivars

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ABSTRACT

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Hard red winter wheat cultivars were inoculated with wheat streak mosaic virus (WSMV) in the fall or spring and then were evaluated in the spring for severity of wheat streak mosaic symptoms, detection of WSMV by enzyme-linked immunosorbent assay (ELISA), fertile tiller production, yield, and thousand kernel weight (TKW). On the basis of these parameters, seven cultivars (Century, Chisholm, Pioneer 2157, Siouxland, Tam 108, Triumph 64, and Vona) were considered susceptible when inoculated with WSMV in the fall. The maximum percent reductions for these seven cultivars over 2 yr of tests in fertile tillers, yield, and TKW were 75, 87, and 48%, respectively. One cultivar, Rall, had some resistance to wheat streak mosaic if planted in the fall during the time recommended for north central Oklahoma. The maximum percent reductions in fertile tillers, yield, and TKW for Rall were 22, 20, and 11%, respectively. Spring inoculation with WSMV of wheat planted early in the fall (September or October) did not consistently result in symptoms, ELISA values positive for WSMV, or significant reductions in yield or TKW. However, spring inoculation of wheat planted late in the fall (November) resulted in symptoms, ELISA values positive for WSMV, and significant reductions in yield and TKW. Thus, the maturity of plants at the time of infection may affect severity of wheat streak mosaic because wheat planted in November was less mature (Feekes' growth stage 5) at the time of inoculation the next spring than wheat planted in September or October (Feekes' growth stage 6).

Wheat streak mosaic virus (WSMV), which causes wheat streak mosaic (WSM), is vectored by the wheat curl mite (*Eriophyes tulipae* Keifer) (16). Wheat curl mites acquire WSMV by feeding on hosts infected with the virus. In winter wheat production areas such as Oklahoma, wheat (*Triticum aestivum* L.) may be infected in the fall or spring by viruliferous wheat curl mites, which spread into cultivated wheat from bordering volunteer wheat or other host plants infected with WSMV. Symptoms of WSM on winter wheat usually appear in the spring and become more severe as the growing season progresses and temperature increases.

Significant yield reductions due to WSM have been reported (2,7,10,11,17, 18), and the importance of planting date on severity of WSM has been documented in states other than Oklahoma. Willis (19) summarized a 10-yr study conducted in South Dakota by W. S. Gardner that examined the effect of planting date on WSM. This study concluded that WSM is most severe in early planted wheat, that late planting decreases WSM dramatically, and that WSM causes severe yield loss. Hansing et al (5) observed that wheat seeded early or late in the fall became highly infected by WSM. He noted that wheat sown in southwestern Kansas during August and early September was most heavily infected whereas wheat sown from 15 to 25 September was the least infected; they also noted that the later wheat was seeded in October, the more severe the mosaic was in the late spring. In contrast, on the basis of field surveys during five successive seasons in Kansas, Fellows and Sill (3) concluded that wheat must be infected in the fall when plants are young for severe yield reductions to occur and that spring infection of winter wheat with WSMV causes no or only slight losses in yield.

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Related to the effect of planting date on WSM is the idea that WSM becomes more severe following infection of young plants. Hansing et al (5) reported that wheat plants infected with WSMV when young were more severely damaged than those infected later. Slykhuis (15) drew a similar conclusion from field observations but also stated that the reverse appeared to be true in other instances. Slykhuis (15) confirmed in greenhouse experiments that the degree of stunting from WSMV may be related to the age of plants at the time of infection but, because of the natural occurrence of WSM, was unable to study the relation of age at the time of infection to the severity of loss in field plots. In a greenhouse study using mechanical inoculation of WSMV, Sill (14) found that wheat plants inoculated before or during early tillering were severely damaged by WSM. Plants inoculated after the four-tiller stage responded more erratically to WSMV, with a small percentage escaping infection and with symptoms developing more slowly. Thus, the present study was conducted to determine the reaction to WSM of hard red winter wheat cultivars adapted to Oklahoma and to determine the effects of WSMV infection in the fall and spring on hard red winter wheat sown at different planting dates.

MATERIALS AND METHODS

Field plot location and design. Studies were conducted during four growing seasons near Stillwater, Oklahoma. Preplant fertilization and liming based on soil tests were conducted to provide appropriate nitrogen, phosphorus, potassium, and pH for wheat production in north central Oklahoma. All plots were planted in a randomized complete block, split-plot design, with three replications in 1986–87, 1987–88, and 1989–90 and four replications in 1988–89. Six hard red winter wheat cultivars (Century, Chisholm, Pioneer 2157, Siouxland, Tam 108, and Vona) were tested in 1986–87 and eight (same as in 1986–87 plus Rall and Triumph 64) were tested

in 1987–88. Results from the first two seasons indicated that Chisholm was highly susceptible and Rall was resistant or tolerant to WSM. Thus, only these two cultivars were tested in 1988–89 and 1989–90.

In 1986–87 and 1987–88, seven 3.05-m rows of each cultivar were planted 25.4 cm apart with 150 seeds per row at a depth of 2.5 cm. Seeds were planted on 16 September 1986 and 2 October 1987. Between each plot of seven rows, an indicator row of Vona was planted to detect the occurrence of wheat soilborne mosaic or wheat spindle streak mosaic.

In 1988–89, the effect of planting date on WSM development in Rall and Chisholm was examined. The plot design and planting procedures previously described were used except that four replications were planted at each of three planting dates: 12 September, 12 October, and 9 November 1988.

In 1989–90, Rall and Chisholm were planted near Stillwater on 21 September 1989, as described for 1986–88. This test was conducted to corroborate information regarding the reaction of Rall to WSMV observed in 1986–87.

In all trials, plots were irrigated if needed in the fall to facilitate emergence and stand establishment and in the spring to alleviate drought stress. Chlorsulfuron (Glean) at 13 g a.i. in 187 L/ha (0.2 oz a.i. in 20 gal/acre) was applied in the fall to control weeds, and triadimefon (Bayleton) at 140 g a.i. in 187 L/ha (2 oz a.i. in 20 gal/acre) was used during the spring as needed to maintain a low incidence of foliar fungal diseases.

WSMV inocula, inoculation, and symptom evaluation. Seedlings of greenhouse-grown wheat (cv. Blue Jacket) were mechanically inoculated with an isolate of WSMV obtained from E. Sebesta (USDA-ARS, Stillwater) as previously reported (12). Eleven to 14 days after inoculation, foliage was cut approximately 2.5 cm above the soil and stored at −20 C until used to make inoculum (a maximum of 2 wk). On the day of inoculation, 100 g of foliage from infected Blue Jacket seedlings was blended with 1.5 L of distilled water for 90 sec at high speed in a Waring blender. The resulting slurry was filtered through cheesecloth, and 50 g of Celite was added. Inoculum was kept in 2-L jars in ice until used to inoculate seedlings in the field. Plants in field plots were inoculated with a DeVilbiss air gun operated from an air compressor and generator. Foliage of seedlings was supported with one hand and sprayed with the inoculum at air pressures of 414 kPa (60 psi) and 517.5 kPa (75 psi) in the fall and spring, respectively. These pressures resulted in the appearance of water-soaking, indicating that inoculum was introduced into the foliage. The second, fourth, and sixth row in each plot were designated at random to be inoculated in the fall or spring or to serve as the uninoculated check. In fall 1986, 10 ml of inoculum was applied to each 0.31 m of row. In all subsequent inoculations, this was increased to 25–40 ml of inoculum per 0.31 m of row to ensure inoculation of all plants within a row.

In 1986–87, plants were inoculated on 21 October 1986 (fall inoculation) or on 27 March 1987 (spring inoculation). In 1987–88, plants were inoculated on 5 November 1987 or 7 April 1988. In 1988–89, plants were inoculated on 4 November 1988 or 24 March 1989. In 1989–90, plants were inoculated on 7 November 1989 or 22 March 1990. Each row was rated for WSM symptoms in the spring using the scale of 0 = no symptoms; 1 = no stunting present, leaves mostly light green with a few yellow streaks; 2 = plants slightly stunted, leaves with mixed green and yellow streaks; and 3 = plants stunted, leaves with severe yellow streaking and a few green streaks or green islands. In 1986–87, plots were rated on 16 April 1987 and 13 May 1987. In 1987–88, plots were rated on 6 April 1988 and 18 May 1988. In 1988–89, plots were rated on 5 April 1989 and 23 May 1989, and in 1989–90, plots were rated on 4 April 1990 and 11 May 1990.

Foliage was obtained after each visual assessment by collecting young leaves from along the entire length of each row. Collected foliage was stored at −20 C until evaluated by enzyme-linked immunosorbent assay (ELISA) (a maximum of 3 mo). A double antibody sandwich ELISA using polyclonal antiserum as previously described (12) was used for evaluation of samples collected in 1986–87. For samples collected in all subsequent years, an indirect sandwich ELISA using both polyclonal antiserum and a monoclonal antibody to WSMV was used (13).

Fertile tiller production was determined just prior to harvest only in the first two seasons by counting the number of tillers with fertile heads in a representative 0.3-m segment of each row in each replication. Wheat was cut by hand, threshed, and cleaned, and grain yield and thousand kernel weight (TKW) were determined. Data pertaining to fertile tiller production, yield, and TKW were analyzed by a split-plot analysis of variance with cultivar as main plot and time of inoculation (i.e., fall, spring, and

Table 1. Reaction of six hard red winter wheat cultivars to wheat streak mosaic in 1986–87

Cultivar Inoculation[a]	16 April 1987		13 May 1987		Fertile tillers[b] (no./0.3 m)	Yield[b] (g)	TKW[b] (g)
	Symptom rating[c]	ELISA[d]	Symptom rating[c]	ELISA[d]			
Century							
Check	0.0	0.09	0.0	0.07	38	737	25
Fall	1.7	0.26	3.0	0.33	16*	138*	13*
Spring	0.0	0.14	1.3	0.16	31	514*	23
Chisholm							
Check	0.0	0.05	0.0	0.08	32	530	29
Fall	1.3	0.18	2.7	0.27	8*	203*	22*
Spring	0.0	0.16	1.3	0.10	24	437*	26*
Pioneer 2157							
Check	0.0	0.09	0.0	0.04	28	507	24
Fall	1.3	0.23	3.0	0.29	14*	145*	18*
Spring	0.0	0.10	1.0	0.13	21	461*	23
Siouxland							
Check	0.0	0.08	0.0	0.09	34	429	24
Fall	1.3	0.32	3.0	0.30	17*	150*	16*
Spring	0.0	0.19	1.0	0.23	31	416	22
Tam 108							
Check	0.0	0.08	0.0	0.07	32	658	28
Fall	0.7	0.17	1.7	0.34	16*	258*	23*
Spring	0.0	0.19	0.7	0.06	24	496*	25*
Vona							
Check	0.0	0.18	0.0	0.11	28	399	21
Fall	2.7	0.26	3.0	0.32	16*	56*	11*
Spring	0.3	0.28	1.7	0.17	21	342*	18*
LSD ($P = 0.05$)					8	42	2

[a] Seeds were planted on 16 September 1986, and inoculations with WSMV were conducted on 21 October 1986 or 27 March 1987.

[b] Each value is the mean from three replications. Asterisks indicate significant difference from the check within cultivar as determined by a LSD mean separation test calculated using the error term $s\bar{d} = [2(E(b)\mathrm{MS})/r]^{1/2}$.

[c] Each value is the mean of three replications rated as 0 = no symptoms; 1 = no stunting present, leaves mostly light green with a few yellow streaks; 2 = plants slightly stunted, leaves with mixed green and yellow streaks; and 3 = plants stunted, leaves with severe yellow streaking and a few green streaks or green islands.

[d] Each value is the mean absorbance (i.e., optical density) at 405 nm of three replications with three readings per replication. Values ≥0.10 are considered positive and values <0.10 are considered negative.

check) as subplot. LSD ($P = 0.05$) was calculated to compare two subplot (inoculation date) means within the same main plot (cultivar) treatment (4). Analyses were conducted within each year for each cultivar.

Statistical analysis of the visual ratings of symptom severity was not conducted because these data were not quantitative. ELISA values were used qualitatively to determine the presence or absence of WSMV. Values <0.10 were considered negative for WSMV and values ≥0.10 were considered positive for WSMV on the basis of values obtained from known positive and known negative material previously assayed (13).

RESULTS AND DISCUSSION

No symptoms indicative of wheat soilborne mosaic or wheat spindle streak mosaic were observed in the indicator rows (cv. Vona) located between replications of each cultivar or in the rows located between the three test rows (i.e., rows inoculated in the fall or spring or not inoculated). Thus, results were not confounded by the occurrence of other viruses known to occur in this area.

Reaction of hard red winter wheat to WSMV in 1986–87 and 1987–88. No symptoms of WSM were observed and only negative ELISA values were obtained in rows inoculated in the fall of 1987 when evaluated on 3 December 1988 (*data not shown*), indicating that WSMV was not detected at 4 wk after inoculation in the fall. Symptoms typical of WSM were observed in all cultivars in April of each year in the rows inoculated with WSMV the previous fall (Tables 1 and 2). These symptoms were severe in all cultivars except Rall by the time of the second evaluation in May (Table 2). Detection of WSMV by ELISA followed this same pattern in each of these two growing seasons (Tables 1 and 2). Differentiation between positive and negative ELISA values was not as clear in 1986–87 as in subsequent years because of the difference in the quality of the antiserum used. The polyclonal antiserum used in ELISA in 1986–87 reacted some with healthy wheat tissue (e.g., cv. Vona in Table 1). In subsequent years, monoclonal antibodies were used and reaction with healthy tissue was eliminated.

No symptoms were noted in April 1987 in rows inoculated 3 wk earlier (i.e., spring inoculation), but positive ELISA values were obtained from five of the cultivars (Century, Chisholm, Siouxland, Tam 108, and Vona), indicating an increase of WSMV capsid protein before the expression of symptoms (Table 1). In April 1988, rows inoculated in the spring with WSMV had readings in ELISA comparable to those of the checks (Table 2) because inoculation was done the day after this evaluation to ensure that no infection had occurred the previous fall or from natural sources (i.e., viruliferous wheat curl mites). Six weeks later (18 May 1988), no symptoms to slight symptoms and negative ELISA values were obtained in all cultivars inoculated in the spring (Table 2). The difference in the development of WSM in plants inoculated in the spring in 1986–87 and those inoculated in 1987–88 may have been due to the maturity of plants inoculated in 1987–88. In 1986–87, inoculation was done on 27 March when plants were between growth stages 5 and 6 on the Feekes scale (8). In 1987–88, inoculation was delayed by inclement weather until 7 April, when plants were between growth stages 7 to 8 on the Feekes scale. It is unlikely that inoculation was not successful. Previous results demonstrated that the appearance of water-soaking is a reliable indicator that infectious inoculum has been introduced into the wheat foliage. Thus, a possible explanation for these results is that plant maturity affects virus replication and development of WSM, with older plants being more resistant than younger plants. These results are consistent with previous reports (9,14,15) and should be considered when inoculating wheat to determine host reaction to WSM.

Pioneer 2157 shows reduced WSM symptoms in the field (1; E. Williams, Jr., and R. M. Hunger, *unpublished*) when compared to other cultivars planted in Oklahoma. In this study, no resistance to WSM was observed in Pioneer 2157 after inoculation in the fall (Table 1 and 2). Thus, the resistance observed in the field may be due to resistance to the mite rather than to the virus or may result from a mechanism such as trichome density as described by Harvey et al (6). These workers reported that wheat cultivars with low trichome densities harbored fewer mites and showed less WSM than cultivars with higher trichome

Table 2. Reaction of eight hard red winter wheat cultivars to wheat streak mosaic in 1987–88

Cultivar Inoculation[a]	6 April 1988 Symptom rating[c]	6 April 1988 ELISA[d]	18 May 1988 Symptom rating[c]	18 May 1988 ELISA[d]	Fertile tillers[b] (no./0.3 m)	Yield[b] (g)	TKW[b] (g)
Century							
Check	0.0	0.01	0.0	0.00	77	235	31
Fall	2.3	1.73	3.0	2.00	19*	31*	17*
Spring	0.0	0.01	0.3	0.00	69*	203	23
Chisholm							
Check	0.0	0.00	0.0	0.01	72	272	29
Fall	1.3	1.67	3.0	2.00	36*	58*	23
Spring	0.0	0.02	0.3	0.00	68	195*	29
Pioneer 2157							
Check	0.0	0.01	0.0	0.00	70	245	36
Fall	1.7	1.44	3.0	2.00	31*	76*	28
Spring	0.0	0.00	0.3	0.00	65	218	27
Rall							
Check	0.0	0.00	0.0	0.00	76	180	35
Fall	1.0	0.61	0.0	0.00	59*	143	32
Spring	0.0	0.00	0.0	0.00	73	221	31
Siouxland							
Check	0.0	0.07	0.0	0.01	73	201	41
Fall	1.0	1.67	2.7	2.00	30*	50*	23*
Spring	0.0	0.02	0.7	0.09	71	195	28*
TAM 108							
Check	0.0	0.00	0.0	0.00	75	324	28
Fall	1.7	1.73	3.0	2.00	42*	64*	19
Spring	0.0	0.01	0.7	0.00	73	271	39
Triumph 64							
Check	0.0	0.01	0.0	0.00	63	172	33
Fall	1.0	0.93	2.3	1.89	31*	82*	31
Spring	0.0	0.01	0.0	0.00	56*	184	34
Vona							
Check	0.0	0.01	0.0	0.00	66	232	23
Fall	2.0	1.66	3.0	1.78	23*	43*	16
Spring	0.0	0.01	0.0	0.00	64	208	23
LSD ($P = 0.05$)					5	68	11

[a]Seeds were planted on 2 October 1987, and inoculations with WSMV were conducted on 5 November 1987 or 7 April 1988.

[b]Each value is the mean from three replications. Asterisks indicate significant difference from the check within cultivar as determined by a LSD mean separation test calculated using the error term $s\bar{d} = [2(E(b)\text{MS})/r]^{1/2}$.

[c]Each value is the mean of three replications rated as 0 = no symptoms; 1 = no stunting present, leaves mostly light green with a few yellow streaks; 2 = plants slightly stunted, leaves with mixed green and yellow streaks; and 3 = plants stunted, leaves with severe yellow streaking and a few green streaks or green islands.

[d]Each value is the mean absorbance (i.e., optical density) at 405 nm of three replications with three readings per replication. Values ≥0.10 are considered positive and values <0.10 are considered negative.

densities. Pioneer 2157 was not included in their study and was not examined by us for trichome density. However, such a mechanism may explain the lower severity of WSM observed in the field on Pioneer 2157 and the lack of resistance shown in our study.

Inoculation of WSM in the fall significantly reduced fertile tiller production of all cultivars in 1986–87 and 1987–88 compared with uninoculated checks (Tables 1 and 2). Yields were significantly reduced after fall inoculation except for Rall. TKW of all cultivars was significantly reduced in 1986–87 after fall inoculation, but in 1987–88 only two (Siouxland and Vona) of eight cultivars had significantly lower TKW after fall inoculation. However, all TKW values from plots inoculated in the fall were lower, and variation among replications accounted for the lack of statistical significance in TKW in 1987–88.

Reductions in fertile tillers, yield, and TKW after spring inoculation in 1986–87 and 1987–88 were less than those after fall inoculation. Yield of five cultivars (Century, Chisholm, Pioneer 2157, Tam 108, and Vona) was significantly reduced in 1986–87 (Table 1) after spring inoculation, but only yield from Chisholm was significantly reduced after inoculation in the spring of 1988 (Table 2). In 1986–87, there were no significant reductions in fertile tillers after spring inoculation, and the TKW of three cultivars (Chisholm, Tam 108, and Vona) was significantly reduced (Table 1). In 1987–88, fertile tillers were significantly reduced in two cultivars (Century and Triumph 64) and TKW was significantly reduced in Siouxland (Table 2). In 1987–88, mild symptoms were observed in Rall and a positive ELISA value was obtained in April, but no WSM symptoms were observed and a negative ELISA value was obtained in May. Fertile tiller production of Rall was significantly reduced (22%) after fall inoculation. Yield and TKW of Rall also were reduced after fall inoculation (20 and 9%, respectively), but these reductions were not statistically significant compared with the checks. Reductions in these three parameters after inoculation in the spring were not significantly different from the uninoculated checks (Table 2). Rall resulted from a single plant selection from the cultivar Scout and was released in 1976 by state and federal personnel at Stillwater as being resistant to WSM. The results from 1987–88 (Table 2) confirmed this reported resistance in Rall and prompted additional testing in 1988–90.

Reaction of Chisholm and Rall to WSMV in 1988–89 and 1989–90. The reactions of Chisholm and Rall to WSMV during 1988–89 and 1989–90 confirmed previous observations of susceptibility in Chisholm and resistance in Rall (Tables 3 and 4). Inoculation of Chisholm in the fall resulted in severe symptoms, positive ELISA values, and significant reductions in yield in both years and a significant reduction in TKW in 1989. By comparison, inoculation of Rall in the fall resulted in no to mild symptoms, positive and negative ELISA values during the subsequent spring, and yields and TKW that did not differ significantly from those of the checks (Tables 3 and 4). These results were consistent for each planting date followed by a fall inoculation and indicate that although Rall most likely supports replication of WSMV, as indicated by positive ELISA values, WSMV does not affect the yield of Rall as it affects the yield from a susceptible cultivar such as Chisholm.

Spring inoculation of Chisholm and Rall planted in September or October in 1988–89 and 1989–90 most frequently resulted in no or only mild symptoms, negative ELISA values, and no significant reductions in yield and TKW (Tables 3 and 4). These results agree with results from 1987–88 (Table 2). However, spring inoculation of these cultivars planted in November resulted in symptoms, positive ELISA values, and significant reductions in yield and TKW (Table 3). These results compare with those obtained from the study conducted in 1986–87 (Table 1) for Chisholm and other cultivars. This inconsistency seen after inoculation in the spring may be related to the maturity of the plants at the time of inoculation. The recommended planting date of wheat for grain production in north central Oklahoma is between 1 and 15 October. Wheat planted in September or October 1988 was at growth stage 6 of the Feekes scale and was 25–36 cm tall at the time of inoculation (24 March 1989). Wheat planted on 9 November 1988 was at growth stage 5 of the Feekes scale, was 18 cm tall at inoculation, and had smaller, less mature foliage than the earlier planted wheat. In this late-planted wheat, symptoms were severe and ELISA values were positive within 8 wk after the spring inoculation, and yield and TKW were significantly reduced (Table 3). As previously discussed, wheat was inoculated 11 days later in the spring of 1987–88 and was between stages 7 and 8 of the Feekes scale, as compared with wheat between stages 5 and 6 at the spring inoculation in 1986–87. Further,

Table 3. Reaction of two hard red winter wheat cultivars to wheat streak mosaic during 1988–89

Cultivar Inoculation[a]	Date of planting	5 April 1989 Symptom rating[c]	5 April 1989 ELISA[d]	23 May 1989 Symptom rating[c]	23 May 1989 ELISA[d]	Yield[b] (g)	TKW[b] (g)
Chisholm							
Check	12 Sept. 88	0.0	0.00	0.0	0.00	111	29
Fall	12 Sept. 88	2.0	0.87	2.8	0.52	21*	22*
Spring	12 Sept. 88	0.5	0.01	0.5	0.02	80*	24
Rall							
Check	12 Sept. 88	0.0	0.00	0.0	0.00	66	24
Fall	12 Sept. 88	0.8	0.38	0.0	0.00	61	26
Spring	12 Sept. 88	0.3	0.00	0.0	0.44	68	25
LSD ($P = 0.05$)						17	6
Chisholm							
Check	12 Oct. 88	0.0	0.00	0.0	0.00	104	30
Fall	12 Oct. 88	2.0	0.61	3.0	0.67	29*	19*
Spring	12 Oct. 88	0.3	0.01	1.0	0.02	106	24*
Rall							
Check	12 Oct. 88	0.0	0.01	0.0	0.00	93	28
Fall	12 Oct. 88	1.0	0.75	0.5	0.26	87	25
Spring	12 Oct. 88	0.0	0.01	0.0	0.30	84	24
LSD ($P = 0.05$)						24	5
Chisholm							
Check	9 Nov. 88	0.0	0.01	0.0	0.01	117	28
Spring	9 Nov. 88	0.8	0.06	2.5	0.97	29*	20*
Rall							
Check	9 Nov. 88	0.0	0.01	0.0	0.00	64	32
Spring	9 Nov. 88	0.3	0.01	1.3	0.50	15*	22*
LSD ($P = 0.05$)						12	2

[a] Inoculations with WSMV were conducted 4 November 1988 or 24 March 1989.

[b] Each value is the mean from four replications. Asterisks indicate significant difference from the check within cultivar as determined by a LSD mean separation test calculated using the error term $s\bar{d} = [2(E(b)\text{MS})/r]^{1/2}$.

[c] Each value is the mean of four replications rated as 0 = no symptoms; 1 = no stunting present, leaves mostly light green with a few yellow streaks; 2 = plants slightly stunted, leaves with mixed green and yellow streaks; and 3 = plants stunted, leaves with severe yellow streaking and a few green streaks or green islands.

[d] Each value is the mean absorbance (i.e., optical density) at 405 nm of four replications with three readings per replication. Values ≥0.10 are considered positive and values <0.10 are considered negative.

Table 4. Reaction of two hard red winter wheat cultivars to wheat streak mosaic in 1989–90

Cultivar Inoculation[a]	4 April 1990 Symptom rating[c]	4 April 1990 ELISA[d]	11 May 1990 Symptom rating[c]	11 May 1990 ELISA[c]	Yield[b] (g)	TKW[b] (g)
Chisholm						
Check	0.0	0.03	0.0	0.02	107	27
Fall	1.3	1.33	1.3	1.94	54*	23
Spring	0.0	0.03	0.0	0.03	111	27
Rall						
Check	0.0	0.01	0.0	0.02	76	25
Fall	0.8	0.01	0.8	0.05	66	24
Spring	0.0	0.00	0.0	0.02	66	22
LSD ($P = 0.05$)					23	NS

[a]Seeds were planted on 21 September 1989, and inoculations with WSMV were conducted 7 November 1989 or 22 March 1990.

[b]Each value is the mean from three replications. Asterisk indicates significant difference from the check within cultivar as determined by a LSD mean separation test calculated using the error term $s\bar{d} = [2(E(b)\mathrm{MS})/r]^{1/2}$.

[c]Each value is the mean of three replications rated as 0 = no symptoms; 1 = no stunting present, leaves mostly light green with a few yellow streaks; 2 = plants slightly stunted, leaves with mixed green and yellow streaks; and 3 = plants stunted, leaves with severe yellow streaking and a few green streaks or green islands.

[d]Each value is the mean absorbance (i.e., optical density) at 405 nm of three replications with three readings per replication. Values ≥ 0.10 are considered positive and values < 0.10 are considered negative.

there was an abundance of foliage and jointing of the tillers in 1987–88. Thus, the wheat inoculated in the spring of 1987–88 was considerably more mature than the wheat inoculated in the spring of 1986–87. This difference in maturity at the time of inoculation may have affected the development and severity of WSM as reported by Sill (14) and discussed in the introduction.

These results have several implications. The recommended controls of WSM are to destroy volunteer wheat and plant winter wheat late in order to avoid infection in the fall. Our data confirm the importance of avoiding WSMV infection in the fall but also indicate that planting late in the fall results during the subsequent spring in less mature wheat that is highly susceptible to WSMV. Infection in the spring of this less mature wheat with WSMV may result in significant reductions in yield and TKW, which emphasizes the importance of eliminating the volunteer wheat that harbors WSMV and the wheat curl mite.

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LITERATURE CITED

1. Bowden, R. L., Brooks, L., and Willis, W. G. 1991. Wheat variety disease and insect ratings 1991. Kans. State Univ. Coop. Ext. Serv. Bull. MF-991.
2. Edwards, M. C., and McMullen, M. P. 1988. Variation in tolerance to wheat streak mosaic virus among cultivars of hard red spring wheat. Plant Dis. 72:705-707.
3. Fellows, H., and Sill, W. H., Jr. 1955. Predicting wheat streak mosaic epiphytotics in winter wheat. Plant Dis. Rep. 39:291-295.
4. Gomez, K. A., and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons, New York.
5. Hansing, E. D., Melchers, L. E., Fellows, H., and Johnston, C. O. 1950. Kansas Phytopathological Notes: 1949. Trans. Kans. Acad. Sci. 53:344-354.
6. Harvey, T. L., Martin, T. J., and Seifers, D. L. 1990. Wheat curl mite and wheat streak mosaic in moderate trichome density cultivars. Crop Sci. 30:534-535.
7. Krall, J. M., Vincelli, P. C., and Beaupré, C. M.-S. 1990. Reaction of winter wheat cultivars to wheat streak mosaic virus, 1989. Biol. Cult. Tests Control Plant Dis. 5:74.
8. Large, E. C. 1954. Growth stages in cereals. Illustration of the Feekes scale. Plant Pathol. 3:128-129.
9. Martin, T. J. 1978. Procedures for evaluating wheat streak mosaic virus resistance. Plant Dis. Rep. 62:1062-1066.
10. Seifers, D. L., and Martin, T. J. 1988. Correlation of low level wheat streak mosaic virus resistance in Triumph 64 wheat with low virus titer. Phytopathology 78:703-707.
11. Shahwan, I. M., and Hill, J. P. 1984. Identification and occurrence of wheat streak mosaic virus in winter wheat in Colorado and its effects on several wheat cultivars. Plant Dis. 68:579-581.
12. Sherwood, J. L. 1987. Comparison of a filter paper immunobinding assay, Western blotting and an enzyme-linked immunosorbent assay for detection of wheat streak mosaic virus. J. Phytopathol. 118:68-75.
13. Sherwood, J. L., Hunger, R. M., Keyser, G. C., and Myers, L. D. 1990. Production of a monoclonal antibody for evaluation of hard red winter wheat cultivars to wheat streak mosaic virus. Food Agric. Immunol. 2:155-161.
14. Sill, W. H., Jr. 1953. Some characteristics of the wheat streak-mosaic virus and disease. Trans. Kans. Acad. Sci. 56:418-424.
15. Slykhuis, J. T. 1952. Virus diseases of cereal crops in South Dakota. S.D. Agric. Exp. Stn. Tech. Bull. 11.
16. Slykhuis, J. T. 1955. *Aceria tulipae* Keifer (Acarina: Eriophyidae) in relation to the spread of wheat streak mosaic. Phytopathology 45:116-128.
17. Watkins, J. E., Doupnik, B., Jr., Elmore, R. W., Klein, R. N., Lambert, J. L., Peterson, L. A., and Nelson, L. A. 1990. Reaction of hard red winter wheat cultivars/hybrids to wheat streak mosaic virus (WSMV), 1989. Biol. Cult. Tests Control Plant Dis. 5:75.
18. Wiese, M. V. 1987. Wheat streak mosaic. Pages 80-81 in: Compendium of Wheat Diseases. American Phytopathological Society, St. Paul, MN.
19. Willis, W. G. 1984. Wheat diseases. Kans. State Univ. Coop. Ext. Serv. Bull. S-23.