Wheat Streak Mosaic Virus on Wheat: Biology and Management

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ABSTRACT. Wheat streak mosaic virus is a virus that infects wheat and is transmitted by the wheat curl mite. This virus is responsible for wheat streak mosaic, a widely distributed disease of wheat that can cause economically important yield losses. The current viral taxonomy, vector biology, disease cycle, and management options of Wheat streak mosaic virus are reviewed in this article.

Key Words: Wheat streak mosaic virus; wheat curl mite

Wheat streak mosaic virus infects both winter and spring wheat (Triticum aestivum L.) in the United States and abroad. Depending on environmental conditions (wet, dry, cool, or hot weather), yield loss because of Wheat streak mosaic virus infections can surpass 60% (Langham et al. 2001a). Wheat streak mosaic virus is transmitted by the wheat curl mite, Aceria tosichella Keifer (Acari: Eriophyidae). Wheat is the preferred host for wheat curl mite and an excellent host for Wheat streak mosaic virus. Both mites and Wheat streak mosaic virus are found on other crops such as corn (Zea mays L.), barley (Hordeum vulgare L.), rye (Secale cereale L.), oat (Avena sativa L.), pearl millet (Pennisetum glaucum [L.]), and sorghum (Sorghum bicolor [L.] Moench) (Sill and Connin 1953, Seifers et al. 1996). The virus also infects wild grasses such as foxtails (Setaria P. Beauv. spp.), needle grasses (Stipa L. spp.), goatgrasses (Aegilops L. spp.), crabgrass (Digitaria Haller. spp.), ryegrass (Lolium L. spp.), brome (Bromus Scop. spp.), cupgrass (Eriochloa Kunth spp.), and others grasses (Sill and Connin 1953, Sill and Aguusio 1955, Brakke 1971, Christian and Willis 1993). No dicotyledons have been found to host Wheat streak mosaic virus. Wheat curl mites also use various wild grasses as their hosts.

In wheat, Wheat streak mosaic virus is often found together with two other mite-borne viruses of wheat, Wheat mosaic virus, formerly known as High Plains virus, and Triticum mosaic virus (Mahmood et al. 1998, Burrows et al. 2009). Both Wheat mosaic virus and Triticum mosaic virus are also transmitted by wheat curl mite (Seifers et al. 1997, Seifers et al. 2009).

Geographic Distribution and Yield Losses

Wheat streak mosaic is a globally distributed disease of wheat. Initially described as “yellow mosaic” in Nebraska in 1922 (Hunger 2010), incidences of wheat streak mosaic have been reported in various states of the U.S., Canada, Mexico, Eastern Europe, Western Asia, and Australia (Table 1).

Reported yield losses in wheat because of Wheat streak mosaic virus infection can be substantial. In Kansas, reported yield losses ranged from 7 to 13% (Hansing et al. 1950, Christian and Willis 1993). An 18% yield loss was recorded during a Wheat streak mosaic virus epidemic in Alberta, Canada, in 1963 (Atkinson and Grant 1967). Wheat streak mosaic virus is reported to be a major limiting factor of wheat production in Texas panhandle (Velandia et al. 2010). Even though the average regional loss in yield potential seemed to be moderate, it is possible to find individual fields that suffer total loss because of Wheat streak mosaic virus infection.

Taxonomy

Wheat streak mosaic virus is a member of the family Potyviridae. The complete nucleotide sequence and the phylogenetic relationships of Wheat streak mosaic virus were reported by Stenger et al. (1998). Wheat streak mosaic virus was originally placed in the genus Rymovirus with other mite-transmitted viruses of Potyviridae. A phylogenetic analysis of Wheat streak mosaic virus using its completed nucleotide sequence demonstrated that it shares most recent common ancestry with the whitefly-transmitted Sweet potato mild mottle virus and not with Ryegrass mosaic virus, the type member of genus Rymovirus. This resulted in the proposal of a new genus within the family Potyviridae, genus Tritimovirus, of which Wheat streak mosaic virus is the type member (Stenger et al. 1998).

Symptoms. On individual leaves, the symptoms of wheat streak mosaic start as small chlorotic lines. As the symptom development progresses, chlorotic lines elongate to form discontinuous yellow to pale green streaks, forming a mosaic pattern in the leaves (Fig. 1). In severe cases, the stripes may coalesce, forming large chlorotic areas (Fig. 2), and commonly result in the symptoms progressing into leaf tissue necrosis and plant death. Stunting is another prominent symptom of infected plants (Fig. 3).

Infected plants often appear first on the field margins as the mites migrate from grassy areas and bordering crops (Hunger 2010). Wheat fields infected with Wheat streak mosaic virus exhibit yellowing and stunting in irregular areas, often at field margins or near weeds or volunteer hosts. As the season progresses, infection may spread and symptoms may appear within field. Wheat curl mites will colonize volunteer wheat growing after hail or heavy rain (Gibson 1957) and may serve as a source of wheat curl mite and Wheat streak mosaic virus for next wheat crops (Somsen and Sill 1970). In fields with heavy infestation of volunteer wheat, symptoms may not necessarily be found first on the field margins but instead be scattered throughout the field around the clumps of volunteer wheat.

Damage. Wheat streak mosaic virus infections reduce root biomass and water use efficiency, making it a serious concern in regions with limited availability of water (Price et al. 2010). Leaf chlorosis and necrosis because of infection by Wheat streak mosaic virus also reduce the photosynthetic capacity of the plant. Infection by Wheat streak mosaic virus may cause plant stunting (Langham et al. 2001b), reduced grain test weight (Atkinson and Grant 1967, Langham et al. 2001b), and reduced seed set (Atkinson and Grant 1967). Grains produced by Wheat streak mosaic virus-infected wheat have higher protein content but yield flour with lower water absorption compared with healthy wheat (Atkinson and Grant 1967). Yield loss because of infection by Wheat streak mosaic virus is correlated with the time of infection. Generally, infection by Wheat streak mosaic virus on early stages of the plant results in higher yield loss (Hunger et al. 1992).

Wheat streak mosaic virus has been reported most frequently on winter wheat yet it also occurs in spring wheat. Spring and winter wheat infected with Wheat streak mosaic virus exhibits similar symp-
Transmission Mechanisms. In the field, *Wheat streak mosaic virus* is transmitted by a mite vector, *wheat curl mite*, *Aceria tosichella* Keifer, the only known vector of *Wheat streak mosaic virus* to crops such as wheat (Slykhuis 1955) and corn (Sill and del Rosario 1959). The wheat curl mite is tiny (<0.3 mm or ~1/100 inch) white, and cigar-shaped (Fig. 4) (Jeppson et al. 1975). It is invisible to unaided eyes. A heavy infestation of the wheat curl mite on a wheat plant induces curling of the leaf blades toward the midribs and distortion of the leaf lamina (Slykhuis 1955). Mites cannot fly, their dispersal is primarily wind assisted (Slykhuis 1955) but their long distance dissemination may be assisted by flying insects (Gibson and Painter 1957). As the host plants decline, the wheat curl mites crawl in large numbers to the tip of the plants. Sometimes piling on the top of each other and forming chains, ready for the next passing wind to carry them (Jeppson et al. 1975).

The life cycle of wheat curl mites consists of an egg, two instars of nymph and an adult. At 25°C (77°F), wheat curl mites complete their life cycle in an average of 7 days (Slykhuis 1955). The wheat curl mites live and feed on the hosts’ green leaves, which are critical for

tombs including stunting, reduced yield and test weight, and increased protein content (Langham and Glover 2005).

### Table 1. Global distribution of *Wheat streak mosaic virus*

| Locations where *Wheat streak mosaic virus* has been reported | References |
|---------------------------------------------------------------|------------|
| United States | Hunger 2010 |
| Nebraska | Hansing et al. 1950 |
| Kansas | Slykhuis 1952 |
| South Dakota | Ford and Lambe 1966 |
| Iowa | McKinney et al. 1966 |
| Ohio | Shahwan and Hill 1984 |
| Colorado | Bowen et al. 2003 |
| Alabama | Burrows et al. 2009 |
| Montana | Burrows et al. 2009 |
| North Dakota | Burrows et al. 2009 |
| Oklahoma | Burrows et al. 2009 |
| Texas | Burrows et al. 2009 |
| Wyoming | Burrows et al. 2009 |
| Canada | Slykhuis 1953 |
| Mexico | Sáénchez-Sáénchez et al. 2001 |
| Argentina | Truol et al. 2004 |
| Slovakia | Kúdela et al. 2008 |
| Rumania | Slykhuis and Bell 1963 |
| Jordan | Slykhuis and Bell 1963 |
| Australia | Ellis et al. 2003 |
| New Zealand | Lebas et al. 2009 |

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Fig. 1. Winter wheat experimental line ‘SD07336’ showing linear streaks developing because of *Wheat streak mosaic virus* infection. (photo: Marie Langham, SDSU).

Fig. 2. Winter wheat ‘Arapahoe’ showing advanced symptoms with streaks coalescing into almost solid yellow areas because of infection by *Wheat streak mosaic virus*. (photo: Marie Langham, SDSU).

Fig. 3. Healthy wheat (A) and stunted *Wheat streak mosaic virus*-infected wheat (B). (photo: Marie Langham, SDSU).
mote survival. High humidity is another key factor in mite survival (Slykhuis 1955). Without food, wheat curl mites can survive for <8 hours at 24°C (75°F) and 30–40 hours at 3°C (36°F), indicating the mite’s weak defense against desiccation (Jepson et al. 1975). The mites overwinter as eggs, nymphs or adults living on the crown of winter wheat or other perennial grass hosts. Adult wheat curl mites can survive for several months at near-freezing temperatures but only 2–3 days at −15°C (5°F) (Slykhuis 1955). Eggs survived longer under sub-zero temperatures; over 25% of eggs exposed to −15°C (5°F) for 8 days were able to hatch when moved to room temperature (Slykhuis 1955).

Wheat streak mosaic virus is transmitted by wheat curl mite nymphs and adults but acquisition of the virus from diseased plant is restricted to nymphs (Slykhuis 1955). Virus acquisition and transmission occurs as the mite feeds. Wheat streak mosaic virus can be acquired from an infected host in as few as 15 minutes of feeding, however transmission efficiency is low (<2%) when acquisition time is short. Longer acquisition (feeding) periods result in higher transmission efficiency (Orlob 1966). At room temperature, Wheat streak mosaic virus is retained within the mite for up to 6 days after acquisition (Slykhuis 1955) but Orlob (1966) found that viruliferous mites kept under 3°C (37.4°F) remained infective for 2 months. Orlob (1966) suggested that slower mite development under near-freezing temperature may play a role in maintaining longer virus retention periods.

Recently, very low rates of virus transmission (0.5–1.5%) were reported to occur via seed produced by plants infected by an Australian isolate of Wheat streak mosaic virus (Jones et al. 2005).

**Disease Cycle.** Fall infections of Wheat streak mosaic virus on winter wheat occur when viruliferous mites move from Wheat streak mosaic virus-infected spring wheat, corn, volunteer wheat, and/or annual grasses onto winter wheat seedlings (Connin 1956, Christian and Willis 1993). Virus infection at this early stage is associated with the greatest yield losses on winter wheat (Slykhuis et al. 1957, Hunger et al. 1992). Infected wheat becomes a source of the virus for subsequent infection of adjacent plants. Winter wheat may become infected by Wheat streak mosaic virus in the spring, but typically spring infections result in insignificant yield losses (Somsen and Sill 1970).

In the spring, Wheat streak mosaic virus-infected winter wheat and perennial grasses serve as sources of virus and mites for spring wheat infection. Mite dispersal in the field is the highest as winter wheat matures, between May and June depending on the weather. Spring wheat planted near infected winter wheat fields during this time is at greater risk of Wheat streak mosaic virus infection (Langham and Glover 2005).

Wheat seeds shattered from spikes by hail may germinate as volunteer wheat. Gibson and Painter (1956) showed that volunteer wheat seedlings grown from mite-infested kernels were immediately colonized. Volunteer wheat may act as “green bridge” where mite and virus populations survive between wheat crops (Gibson and Painter 1957, Thomas and Hein 2003). Wet weather in summer that facilitates lush growth of volunteer wheat also supports high population of mites and Wheat streak mosaic virus for subsequent winter wheat infection (Connin 1956, Christian and Willis 1993, Thomas and Hein 2003).

**Management.** Volunteer wheat within wheat fields serves as a critical source of mites and early season Wheat streak mosaic virus infection (Thomas et al. 2004). Elimination of potential sources of mites and Wheat streak mosaic virus before planting also limits the risk of early Wheat streak mosaic virus infection (Slykhuis 1955). Destruction of volunteer wheat and wild grasses in a field two weeks before planting through conventional tillage or with herbicide applications has been shown to suppress the size of subsequent mite populations migrating into wheat (Thomas et al. 2004). In dry conditions, quicker results were obtained through tillage compared with glyphosate herbicide in controlling the volunteer wheat and subsequent mite populations. Under wet weather, glyphosate herbicide and tillage were equally effective. As many nonselective herbicides may require several days or weeks to destroy all green leaf tissues, it is recommended that weed and volunteer wheat are destroyed at least three weeks before planting (Thomas et al. 2004, Jiang et al. 2005).

In areas where spring and winter wheat season overlap, early planting of spring wheat reduces, but does not eliminate the risk of mite infestation, virus introduction and subsequent Wheat streak mosaic virus infection. Seeding winter wheat after the nearby winter or spring wheat crops mature and mite populations associated with these crops decline is recommended (Slykhuis et al. 1957, Hunger et al. 1992). Optimum window for sowing wheat differs depending on the region. Local Cooperative Extension Resources should be able to identify the locally relevant planting date range. Spring wheat should not be sown nearby infected winter wheat fields to avoid exposing the spring wheat seedlings to early Wheat streak mosaic virus infection. Spring wheat should also not be interseeded with winter wheat to limit movement of mites and viruses from maturing winter wheat to spring wheat seedlings (Langham and Glover 2005).

Wheat varieties with resistance to the wheat curl mites were shown to provide some protection against Wheat streak mosaic virus infection (Martin et al. 1984). However, biotypes of wheat curl mite that are able to overcome the resistant genes have developed in some regions (Hein 2010). Wheat with resistance against Wheat streak mosaic virus is another important tactic to manage the disease. An experimental wheat line ‘KS91H184’ was shown to dramatically reduce the viral transmission efficiency of wheat curl mite (Harvey et al. 2005). Temperature-dependent resistance was reported on two experimental winter wheat lines, ‘CO960293’ (Seifers et al. 2006) and ‘KS03H112’ (Seifers et al. 2007). Strains of Wheat streak mosaic virus failed to infect both wheat lines at 18°C (64.4°F) but the resistance broke down at 24°C (75.2°F). ‘RonL’ is a released hard white wheat variety with Wheat streak mosaic virus temperature-dependent resistance derived from experimental line CO960293. Because the resistance in RonL breaks down under high temperatures, planting is recommended in the months with cool temperature after the fall (Martin et al. 2007). Wsm1 is a gene conditioning resistance against Wheat streak mosaic virus identified from intermediate wheat grass (Thinopyrum intermedium) (Friebe et al. 1996). Wheat lines with Wsm1 gene showed resistance against Wheat streak mosaic virus in field conditions, as indicated by lack of symptoms and minimum yield loss (Seifers et al. 1995, Sharp et al. 2002). Mace is a released hard red winter wheat variety with Wsm1 gene. In prerelease field studies, winter wheat variety ‘Mace’ showed less stunting and other Wheat streak mosaic virus-related symptoms compared with susceptible controls and comparable yield to Wheat streak mosaic virus-tolerant variety, ‘Millennium’ (Graybosch et al. 2009).

There is a variable degree of tolerance against Wheat streak mosaic virus among wheat varieties. Tolerant varieties infected by Wheat streak mosaic virus will generally suffer less yield loss than susceptible wheat varieties (Langham et al. 2001b). The hard red winter
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