# A REVIEW OF WHEAT STREAK MOSAIC

by

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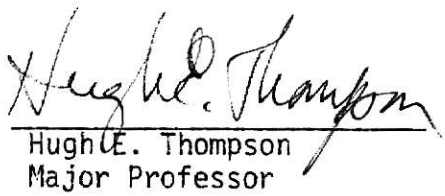

Hugh E. Thompson
Major Professor

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# Chapter 1

## INTRODUCTION

Wheat streak mosaic (WSM) is a virus disease of wheat which can cause serious crop losses. To date, there are no wheat streak mosaic resistant cultivars of wheat available to growers. However, certain cultural practices may be used to reduce the incidence of virus infections. More research is needed if resistant cultivars and chemical control measures are to be developed.

The host-vector-pathogen relationships of wheat, the mite vector, (*Aceria tulipae* (Keifer)), and the wheat streak mosaic virus (WSMV) have been well documented (Connin and Staples, 1957; Maramorosch, 1969; Slykhuis, 1953). Understanding much of the available literature about these relationships requires a background in entomology, plant pathology, crop production, and virology. An attempt is made to provide basic information about WSM and its occurrence in Kansas.

Chapter 2

# HISTORICAL IMPORTANCE

Today's wheat crop occupies an estimated 20% of the world's cultivated land. Eighty percent of this crop is produced in three areas, Europe, the USSR, and the United States; with Kansas, with 12-14,000,000 acres, the leading wheat-producing state within the United States (Lengkeek, 1979).

The disease, wheat streak mosaic, occurs in many parts of the world including Canada, Europe, the USSR, and in several countries surrounding the Black Sea (Harris and Maramorosch, 1980; Lengkeek, 1979; Smith, 1972). It is now widespread in the Great Plains Region of the United States and probably was first observed in this area in Nebraska in 1922. It was identified in Kansas in 1932 by McKinney, from samples taken from test plots near Manhattan (Hansing, et al., 1950; Maramorosch, 1969; McKinney, 1932).

Wheat streak mosaic virus (WSMV) is found in all regions of Kansas except the southeastern region. It is probably the most destructive disease in southwestern Kansas and ranks as one of the most important diseases statewide (Lengkeek, 1979; Willis, 1981). Its severity depends upon weather and environmental conditions during the previous crop year. Also, certain cultural practices can affect the extent of the disease infection (Diseases of Wheat in Kansas, 1955; Niblett, et al., 1974).

The first WSM epidemic in Kansas occurred in 1949, when it caused an estimated 7% loss (15.5 million bushels); valued at 30 million dollars (Fellows, 1949; Hansing et al., 1950).

A second epidemic occurred in 1959 affecting some 20% of the Kansas wheat crop or four million acres and 46,670,000 bushel loss. Losses would have been much greater if it were not for the fact that 40% of the Kansas wheat crop had been planted with mosaic tolerant cultivars; Bison, Kiowa, Triumph, and Concho (King and Sill, 1959).

In 1981, WSM was widespread in Kansas with losses estimated at 7% or approximately 21,350,000 bushels. However, unfavorable Kansas weather that year included a late frost on May 10th and 11th and flooding in late May and June; hence, some exacting WSM loss estimates were difficult to determine (Sim and Willis, 1981).

The 1981 epidemic demonstrated the limited value of mosaic tolerant cultivars. The Scout-type resistance was overcome by high fall temperatures. The Triumph Trison-type resistance, though more heat stable, was not sufficient to prevent severe losses (Willis, 1981).

Because WSM is capable of causing such severe losses, attempts have been, and are being made to discover the factors that contribute to its epidemiology. This information should be useful in predicting future epidemics. Attempts are being made to find and develop new wheat lines with high levels of resistance while chemical control, so far ineffective, may yet be developed.

# Chapter 3

## EPIDEMIOLOGY OF WHEAT STREAK MOSAIC

Wheat streak mosaic (WSM) is a disease caused by a virus pathogen which is vectored (transmitted) by the wheat curl mite, *Aceria tulipae* Keifer. The virus attacks only monocotyledonous plants, those in the grass and lily families (Sill, 1953; Sill and Agusiobo, 1955).

### Symptoms

Symptoms of WSM vary with the host plant, time of infection, virus strain and environmental conditions (Kainski, 1955; Niblett et al., 1974; Rosario, 1957; Wiese, 1977). On wheat, early symptoms are faint chlorotic dashes or light green to yellow streaks that run parallel to the leaf veins and become more visible as the disease progresses. Infected plants may exhibit stunting, tiller death, and sterile or partially filled heads. In cases of severe infection, the entire plant may die (Brakke, 1971; Harris and Maramorosch, 1980; Slykhuis, 1955; Smith, 1972). Under ideal conditions, symptoms develop in six to eight days (Smith, 1972).

During the early stages of the disease, the symptoms are difficult to distinguish from nitrogen deficiency, cold temperature injury, chemical injury, and other plant diseases (Uyemoto and Ferguson, 1980). Rolled leaves, and beards of heads trapped in the rolled leaves, are also included as a symptom associated with WSM. However, these were caused by mite feedings (Slykhuis, 1955; Somsen and Sill, 1970).

Disease symptoms are evident in late March to early May and disease distribution in the field allows a tentative distinction between wheat streak mosaic and wheat soil borne mosaic. Both diseases are caused by viruses, and plant symptoms of the two are very similar. Wheat streak mosaic spreads across a field in a blanket pattern and usually spreads from the windward side of the field. This occurs because wind is the primary disperser of the mite vector. Wheat soil borne mosaic, on the other hand, appears primarily in low areas throughout the field since the vector of soil borne mosaic is a fungus which moves within the soil and does not rely on wind for dispersal.

Several factors must usually be present before WSM is considered a severe epidemic.

> "1. The virus must be very widespread and abundant to do great damage.
> 2. Wheat plants must be infected in the fall when plants are young if yield reductions are to be severe.
> 3. Spring infections of winter wheat have caused only slight losses, sometimes none, even in susceptible varieties." (Borgman et al., 1981; Fellows and Sill, 1955.)

The wheat streak mosaic virus multiplies within the plant and utilizes energy, produced by the plant, that is necessary for plant growth and seed formation. Actively growing tissues are the most suitable host for multiplication of the virus and feeding of the mites; while mature plants are not suitable hosts for the vector (mite) or the virus.

Hence, if established plants are infected in the Spring, the virus will not multiply to levels necessary to cause yield reduction, before plant maturity.

Unlike some other wheat diseases, e.g. tan spot, once the plants are dead, they are not a source of virus inoculum. As plants senese, the mites disperse to a new food source and the virus is destroyed as the plant tissue decomposes (Diseases of Wheat in Kansas, 1955).

## Factors Affecting Disease Development and Expression

Environmental conditions affect the incidence and expression of the disease. Borgman (1959) determined that there is a five-month period when weather factors can be crucial to the spread of the disease. Temperature is perhaps the most important environmental condition affecting the spread and development of WSM since it has been observed to be most severe during warm or hot weather (Diseases of Wheat in Kansas, 1955).

From July to November the mite's survival is dependent upon finding a suitable host, and spread of the disease is dependent upon the mite's survival. The mite is most active and reproductive during warm weather. Early planting may expose wheat to a longer period of warm weather thus permitting mite populations to increase and spread within the field (King and Sill, 1959; Slykhuis, 1955).

Warm weather, above 17°C, also allows more rapid multiplication and movement of the virions within the plant. Infected plants become more affected the longer the virus is allowed to multiply and spread, therefore, extended warm weather allows greater yield loss to occur (Niblett et al., 1974; Slykhuis, 1955). Extended hot, dry weather also weakens the plants. However, plants that are adequately fertilized and provided

with sufficient moisture are more vigorous and, therefore, more capable of withstanding disease infection (Niblett et al., 1974).

Other important environmental factors include wind and hail. Wind is the primary method of dispersal of the vector, *Aceria tulipae*. The mites move around on the plant by crawling, but their small size severely limits the distance traveled. Mite movement within a field and between fields is by wind.

Hail is also important as hail damage weakens plants, causing plant stress and seed heads shatter upon impact by dropping hail. Such shattered heads give rise to viable kernels which then germinate and become a volunteer wheat crop. In the 1959 WSM epidemic, the conditions following the 1958 wheat harvest enhanced the growth of volunteer wheat thereby providing a suitable oversummering host for multiplication of the vector (*A. tulipae*) and the virus. Adequate soil moisture allowed for early planting of the 1959 wheat crop (King and Sill, 1959) and once the crop was established, the mites moved into it in large numbers. Early planting, followed by extended warm Fall weather, allowed the disease to reach epidemic proportions (Smith, 1968). The mites were able to reproduce and feed much later than usual, allowing them time to spread the disease throughout many fields. By Spring, much of the crop was infected and severe losses resulted.

In contrast, the epidemic of 1981 was unexpected for several reasons. During the Summer and Fall of 1980, Kansas experienced a severe drought which prevented any extensive volunteer wheat growth to serve as host to the vector and virus. Also, due to lack of adequate moisture, much of the 1981 crop was planted and/or emerged later than usual. These factors should have caused a reduction in the number of mites surviving until the emer-

gence of the new wheat crop. However, the extended Fall weather allowed the initially low mite population to increase before Winter.

In 1981, warm Spring weather arrived earlier than usual (Willis, 1981) which allowed the mites to spread within the crop and transmit the disease earlier than usual. Late April surveys showed one percent of the plants infected with WSM (due to Fall infections). A second survey, three weeks later, revealed 100% infection (Martin, 1981).

Another variation noted in the 1981 epidemic was the atypical field development. Wheat streak mosaic is usually most severe on the edge of the field closest to the mite source. The disease normally decreases in severity with distance from the edge source. Minimal losses can usually be expected beyond a distance of ¼ mile from the source (Willis, 1981). The 1981 crop, however, exhibited uniform and severe infection much farther from the source. Even fields without an obvious infection source were severely infected (Willis, 1981).

This atypical pattern of infection might be explained by the enormous mite populations permitted by the extended warm weather. With high population developed in the Fall, the mites were able to spread over and infect areas much larger than in normal years. Cold Winter weather usually prevents such a buildup of mite populations.

## Host Range of Wheat Streak Mosaic

### Crop Hosts

Numerous host range studies have been conducted on WSM. Five authors agree on only a few of the plants tested. Their results are compiled in Table 1.

The most important host of WSMV is winter wheat. Wheat streak mosaic virus may infect several Spring-sown crops, but the disease is only found where winter wheat is grown nearby (Maramorosch, 1969). Because of this, volunteer wheat is a very successful Summer host, and plays a significant role in the oversummering of the disease (Maramorosch, 1969; Smith, 1968; Willis, 1981). Both the vector and virus of WSM require a continuum of living hosts to survive (Harris and Maramorosch, 1980). Any break of longer than six days in the succession of hosts will reduce the survival of the mite, *A. tulipae*, and subsequently the virus. Because of this, eradication of volunteer wheat is an important method for controlling WSM.

Other crops suspected of serving as alternative hosts to WSMV include oats, rye, barley, millet, sorghum, and corn (Borgman, 1959; Finley, 1957; Harris and Maramorosch, 1980; Lengkeek, 1979; Somsen and Sill, 1970; Wiese, 1977). Oats, rye, and barley are listed by some authors as susceptible, and by others as resistant to the virus. The capability of these plants to support an increase in mite population is also disputed (Borgman, 1959; Harris and Maramorosch, 1980; Lengkeek, 1979; Somsen and Sill, 1970).

Proso millet is listed as a susceptible host of both the mite and the virus (Lengkeek, 1979; Somsen and Sill, 1970). Sorghum, on the other hand, is immune to the virus, but susceptible to the mite. Borgman (1959) notes that sorghum's importance may in fact be in serving as a temporary host to the mites for up to 26 days.

Corn is the crop that most authors agree is a suitable alternative host susceptible to both the mite and the virus (Brakke and Ball, 1968; Finley, 1957; Gates, 1970; Lengkeek, 1979; Nault and Styer, 1969; Nault,

1970; Smith, 1972; Wiese, 1977). Somsen and Sill (1970) note that the mite *Aceria tulipae* was rarely found on corn in Kansas. However, WSMV is one of the viruses involved in Corn Lethal Necrosis which occurs in northcentral Kansas and requires us to view corn as a host in Kansas.

In Ohio and Ontario, corn has been reported by Nault (1970), Nault and Styer (1969), and Gates (1970) as being naturally infected with WSMV in the field. Shao Chung How (1962) found hybrid seed corn fields in central Nebraska infected with WSMV in the summers of 1959, 1960, and 1961. Finley (1957) also observed WSM on sweet corn in Idaho.

On the corn, the symptoms of WSM vary from mosaic coloring and dwarfing in inbred lines to simply mosaic coloring in hybrid lines. Ears on the infected plants were poorly developed and kernels were widely spaced, however, the kernels that did develop were normal and germinated readily (Finley, 1957). Brakke and Samson (1981) noted that WSMV is one of the three viruses capable of inducing abberant ratio, a virus induced mutation in corn.

*Aceria tulipae* feeds on the corn leaves until they become too tough to roll or penetrate. Thus, leaves that are easily rolled provide the best protection for the mite (Connin, 1956). The mites migrate from tough leaves, upward into the developing ears. Another symptom on corn caused by the mites feeding is Kernel Red Streak, which is a red stripped discoloration of the kernels (Gates, 1970).

As the corn nears maturity in the Fall, the mites disperse into nearby wheat fields. Then, in the early Summer, as the wheat heads dry, the mites move into the seedling corn fields. This succession of susceptible hosts may allow the build-up of high mite populations and with the increased mite populations, the threat of WSMV infection in both corn

and wheat rises, posing a serious threat to corn and wheat production in the Corn Belt States (Niblett et al., 1974).

Non-Crop Hosts

A study in 1966 by Orlob, indicated that wild grasses were of little importance in the epidemiology of the disease. Orlob found that most of the grasses were either immune to the virus or did not support an increase in mite populations. Borgman (1959), however, had listed jointed goatgrass, hairy grama, sandbar, Canadian wildrye, and green foxtail as possibly of major importance in the spread of WSM.

Approximately 15 perennials have been successfully infected, either artificially or naturally, with WSMV in the United States. Some have been observed infected in the field, but laboratory tests show that none are susceptible to both the mite and the virus (Harris and Maramorosch, 1980).

Chapter 4

# THE VIRUS

The vector of wheat streak mosaic virus is an arthropod, specifically, the wheat curl mite, *Aceria tulipae* (Keifer), which carries the WSM virus particles within its body. The particles are then introduced into the plant through the feeding action of the mite.

## Classification

Viruses, in general, can be divided into two groups dependent upon the location of the virus particles in or on the vector's body. The stylet-borne, nonpersistent viruses, are carried on the mouth parts (stylets) of the vector. These viruses are classified as nonpersistent because the virus particles do not move into the vector's body and are shed with the skin during molting. The stylet-borne, nonpersistent virus particles are filamentous and readily transmitted by sap innoculation.

The circulative, persistent viruses are acquired by the vector during feeding periods of 15 minutes or longer. The virus particles are taken in and circulate within the vector's body. The WSM vector remains infective through molting and is capable of transmitting the virus for up to nine days after removal from a virus source in tests conducted at 20-25°C (Harris and Maramorosch, 1980; Maramorosch, 1969).

Wheat streak mosaic virus is unusual because it has characteristics of both groups. The virus particles are filamentous and readiy sap trans-

mitted, like the stylet-borne group. However, the particles also 1) circulate within the mite (*Aceria tulipae*), 2) persist through molting, and 3) are acquired during long feeding periods like the circulative group (Harris and Maramorosch, 1980; Maramorosch, 1969).

## Morphology

The virus particles of WSM are filamentous, approximately 700nm long and 15nm in diameter. They possess ribonucleic acid (RNA) and have a helical symmetry (Brakke, 1971; Corbett and Sisler, 1964).

The pathogen was recognized through the use of filtered extracts of diseased plants before the vector was known. Various authors noted the presence of polyhedral particles 16 to 18nm in diameter within plant and mite tissues. Several scientists have set forth the theory that these shorter particles possibly join together to form the typical WSM virus long rods. These particles may possibly be ineffective forms of the WSM virus, or particles of a contaminating virus (Smith, 1972).

## Test Characteristics of Wheat Streak Mosaic Virus

The particles of WSMV can be distinguished from other viruses by various tests. Several of these identification tests are outlined below.

A. Sap innoculation tests differentiate between the stylet-borne and circulative viruses.

B. Host range tests study the susceptibility of various plants to the disease in question. Wheat streak mosaic virus can be differentiated from Agropyron mosaic virus

only by the fact that *Agropyron repens* is susceptible to Agropyron mosaic virus and not to wheat streak mosaic virus. The particles of Agropyron mosaic virus and wheat streak mosaic virus are visually identical (Smith, 1972).

C. Inactivation tests involve subjecting liquid extracts of the virus to different temperatures. Wheat streak mosaic virus is inactivated when plant sap extracts are subjected to 55°C for 10 minutes. Virus life is lengthened with decreasing temperatures (Kainski, 1955; Smith, 1972). The virus survived for 350 days at a temperature of -23°C (Kainski, 1955).

D. The longevity test of infectivity aids in identification of viruses in plant juices or desiccated plant tissues. Wheat streak mosaic virus can remain infective for over one year if desiccated in plant tissues and stored over calcium chloride (Kainski, 1955; Smith, 1972). However, the virus loses infectivity rapidly when plant tissues are dried under normal conditions. Infectivity is also rapidly lost when green leaves are preserved in moist conditions at room tempera-

ture. The significance of this fact is seen in the fact that no active virus remains in plants which die in the field or in stubble following harvest. Therefore, dead plants and stubble do not serve as sources of infection to other plants (Kainski, 1955; Sill, 1953; Smith, 1972).

E. Serology tests assist in virus identification. In the precipitation reaction test, unidentified antigens (pathogens e.g. wheat streak mosaic virus) are subjected to a laboratory procedure which will yield precipitates. Should the unknown virus be the wheat streak mosaic virus, it will yield an identifiable precipitate.

(See Appendix A.)

Chapter 5

# THE VECTOR

The order *Acari* encompasses mites and ticks. All of the known vectors of plant pathogens in the order *Acari*, belong to the family *Eriophyidae* (Harris and Maramorosch, 1980). Slykhuis (1953) announced that *Aceria tulipae* (Keifer), a species of Eriophyid mite, is the vector which spreads wheat streak mosaic.

Adult Eriophid mites, including *A. tulipae*, have elongated, whitish, spindle or cigar-shaped bodies with two pairs of legs, in contrast to the other families in the order *Acari* which possess four pairs of legs. (See Plate II.) A basic knowledge of the morphology of the mite aids one in understanding the spread of the disease.

## Internal Morphology

### Digestive System

The digestive system of mites is basically a simple tube, consisting of a foregut, midgut, and hindgut (Baker and Wharton, 1952). There is no connection, in adult mites, between the midgut and hindgut (Maramorosch, 1969). The hindgut of Eriophyid mites functions as an excretory organ which opens to the outside through the anal opening, which acts as a uropore (Baker and Wharton, 1952). (See Plate I.)

## Respiratory System

Respiratory structures are variable within the order *Acari*. *Aceria tulipae* has no tracheal system, therefore respiration must occur through either anaerobic reactions or exchange through the cuticle. The small size of these mites is, no doubt, a factor in the success of a non-tracheal respiratory system (Baker and Wharton, 1952).

## Water Exchange System

One of the Eriophyid mites outstanding anatomical features is the presence of microtubercles which are situated within the abdomen in transverse rings. They are thought to control water exchange through the epidermis. In any case, mites have an efficient water exchange system which is necessary to prevent desiccation and subsequent death (Corbett and Sisler, 1964; Harris and Maramorosch, 1980).

# Life Cycle and Reproduction

The life cycle of *A. tulipae* is relatively simple. The cycle consists of four stages: the egg, first nymphal instar, second nymphal instar, and adult. Nymphs resemble small adults but lack external genitalia and vary in microtuberculation (Harris and Maramorosch, 1980). Following the second nymphal instar is a resting period or "pseudopupa," during which the genitals are formed and protrude through the abdominal wall (Maramorosch, 1962).

All mites are dioecious with both males and females occurring year round. Feeding and reproduction also occur year round (Harris and Maramorosch, 1980) with *Aceria tulipae* having an eight to ten day period

between generations (egg to egg) at 75° to 78°F (Staples and Allington, 1956).

All Eriophyid males hatch from unfertilized eggs (parthenogenesis) and are usually smaller than females. Males of the species *A. tulipae* are rarely observed (Harris and Maramorosch, 1980; Maramorosch, 1962).

Fertilization is internal but the mites do not copulate. The males deposit spermatophores, packets containing spermatozoa, on the host surface. When a female crawls over a spermatophore, the sperm are squeezed into her spermatheca, a storage sac within the female reproductive system.

Each female mite is capable of laying between 12 and 20 eggs. del Rosario (1959) and del Rosario and Sill (1958) found that temperature affected reproduction activity. At 0°C the mites did not reproduce; at 7°C populations increased slowly and at 24°C populations increased rapidly. Under ideal conditions, in which all eggs would hatch and all young survive, each mite could produce 3 million descendants in sixty days (Somsen and Sill, 1970).

## Survival

Slykhuis (1955) found that mite survival is based upon a relationship between temperature, relative humidity, and a continuum of hosts. At high temperatures, mites require high relative humidities to avoid desiccation. Slykhuis (1955) demonstrated this in laboratory experiments in which he held the temperature constant at 25°C and varied the relative humidity. He found survival best at 100% relative humidity, reduced with decreasing humidity, and at 25% relative humidity, no mites survived. Mites or their eggs seem capable of surviving the lowest temperatures in

which wheat varieties grown in Alberta, Canada can survive (Slykhuis, 1955).

Because mites are easily desiccated, as seen in Slykhuis' tests, they must locate or produce a high humidity environment to avoid water loss. The mites accomplish this by staying within rolled leaves of the host (Slykhuis, 1955; Somsen and Sill, 1970), which have rolled in response to the feeding of the mite. This enclosed area then provides protection against water loss.

*Aceria tulipae* spends the winter on an overwintering host, which is usually wheat. Reproducing in the Spring, the mites then move to an oversummering host where they continue to multiply throughout the Summer. In the Fall, the mites move back onto an overwintering host.

If there is a break in the continuity of hosts for more than six days, the mites will rapidly die out and populations will drop to very low levels (Corbett and Sisler, 1964; Maramorosch, 1969; Slykhuis, 1955). Even when a continual succession of hosts are supplied, few of the mites will survive their random dispersal by wind to become established. However, survival of the few that reach an acceptable host is sufficient to give rise to a new infestation (Connin, 1956).

## Dispersal

When leaving a plant, the mites crawl to the uppermost plant portions and stand up. The mites actually hold their bodies perpendicular to the leaf surface and use their anal suckers to adhere to the leaf. Air movement over the leaf surface stimulates this perpendicular standing and chain formation, standing one on top of another, (Nault and Styer, 1969). (See Plate IIIB.) Once the mites are upright they are easily carried

off by the wind (Gibson and Painter, 1957).

*Aceria tulipae* begins to disperse from old to new host plants as the old plants mature. Early dispersal is observed when the host plant dies prematurely. Only adult mites exhibit dispersal behavior unless the host plant undergoes extreme and rapid deterioration, in which case the immature forms may also disperse (Nault and Styer, 1969).

Early studies by Rosario, M.S.E. (1957), showed *Aceria tulipae* to be negatively phototropic. Rosario suggested this was the reason that mites were found most abundantly in the darker ligule and leaf axil sections of the plant.

Nault and Styer (1969) pointed out that *A. tulipae* has been observed to move out onto the leaf tips prior to dispersal. They suggested that the mites are negatively phototropic under those conditions which support mite survival and reproduction. However, when food supplies decrease or become less available, e.g. as the host matures, the mites then respond positively to light stimulus (positively phototropic) and move to higher, more exposed locations on the plant where they begin dispersal behavior.

It has been observed that mites usually disperse at the same general time. Such a migration of thousands of mites gives the impression of "swarms" of fuzzy appearing, seething masses, moving to the uppermost portions of the plant (Gibson and Painter, 1957).

The size of the mite severely restricts the distance it can crawl (Corbett and Sisler, 1964). Because they are incapable of crawling from field to field, wind has been accepted as the most important mode of dispersal (Corbett and Sisler, 1964; Maramorosch, 1962; Smith, 1972; Wiese, 1977). However, because wind is a random form of dispersal and mites have no known control over the direction or distance they are

carried, only a small percentage of the dispersed mites reach a suitable new host (Connin, 1956).

Researchers trapped mites on gel-coated slides being used in aerobiological investigations of rust spores in June and July of 1954. The fact that the slides were 1½ to 2 miles away from the nearest wheat field and 150 feet above ground level on top of a building, supports the theory that wind is important in long distance dispersal of *Aceria tulipae* (Smith, 1972).

Although dispersal of *A. tulipae* by insects such as aphids and thrips is not a major dispersal phenomenon, its importance lies in the ability of the insect to deposit the mites directly onto a suitable host (Gibson and Painter, 1957). Maramorosch (1962) studied insects as possible dispersal agents of *A. tulipae*. Observations showed that when aphids and thrips moved along the wheat plants, they came in contact with migrating mites moving up the plant. The mites were observed to crawl onto the insect's body and remain attached by their anal suckers despite attempts by the carrier insect to "scratch" the mites off. The mites were still present when the insect took flight (Connin and Staples, 1957; Gibson and Painter, 1957).

## Intake and Transmittance of the Wheat Streak Mosaic Virus

### Intake

Eriophyid mites have piercing-sucking mouthparts consisting of five mouth stylets. Two of the stylets are actually modified chelicera in which the moveable digit has become rigid and stylet-like. These modified chelicera act as the sole effective piercing elements (Harris and

Maramorosch, 1980). The two stylets located behind the modified chelicera are auxillary stylets and are believed to inject digestive enzymes into the plant tissues (Harris and Maramorosch, 1980). The fifth stylet is very thin and small and it moves up and down behind the other stylets aiding in intake of the plant juices (Harris and Maramorosch, 1980).

Wheat streak mosaic virus particles are taken in by *Aceria tulipae* with the plant juices. The particles circulate within the vector's body (Bawden, 1964; Harris and Maramorosch, 1980). There is no evidence that the virus particles multiply within the mite's body, rather, particles are thought to accumulate during repeated feedings of 15 minutes or more (Harris and Maramorosch, 1980). Within the body of *A. tulipae*, the virus particles accumulate in the midgut region, although particles can be found in the body cavity tissue and salivary glands (Harris and Maramorosch, 1980). The particles remain infective within the mite's body for a minimum of five days (Harris and Maramorosch, 1980; Slykhuis, 1955) and up to nine days (Maramorosch, 1969).

Transmittance

*Aceria tulipae* is capable of transmitting the virus particles of wheat streak mosaic to healthy plants. Two pathways are theorized as possible methods of transmittance.

1. The virus may be injected along with digestive enzymes secreted by the salivary glands. The presence of virus particles in the salivary glands would seem to support this theory.
2. Maramorosch (1969) theorizes that particles

> excreted from the mite (through the uropore) enter the plant through the puncture injury created by feeding, or through an abrasion created by the rubbing action of the anal suckers which hold the mite to the leaf.

Transmittance tests have shown that both nymphs and adults can transmit the virus but only nymphs can acquire the virus (Bawden, 1964). The virus is not passed on from the adult to the eggs. As a result, all eggs hatch into nonviruliferous mites. (See Appendix B.)

## Hosts of the Mite, *Aceria tulipae* (Keifer)

*Aceria tulipae* was first collected in Sacramento, California, and was believed to have been imported into the United States in tulip bulb shipments from Holland (Kainski, 1955). It was first described by Keifer in 1937. It now has several common names; the wheat curl mite, the tulip bulb mite, and the dry bulb mite (Sill and Agusiobo, 1955).

It is rare for any Eriophyid mite species to have hosts in more than one plant family (Harris and Maramorosch, 1980). One exception is *Aceria tulipae*, which breeds on members of both the grass and lily families (Harris and Maramorosch, 1980). The mite has successfully colonized various members of these plant families since its introduction into the United States. Baker and Wharton (1952) discussed the habitat of *Aceria tulipae* (K) in particular as follows:

> "The eriophyid with the most peculiar habitat that has come to notice so far is the onion or bulb eriophyid, *Aceria tulipae* (K.). Liliaceous bulbs such as onions, garlic and tulips are

> attacked, the mites living between the bulb layers. The mite lives underground, a habitat not known to be possessed by any other species. The activities of *Aceria tulipae* cause the bulb to shrink and dry out. These mites persist in storage." (Baker and Wharton, 1952;158.)

Interest in the biology of *Aceria tulipae* increased when Slykhuis announced in 1953 that the mite was the vector of WSMV (Slykhuis, 1953). Extensive tests of the effectiveness of the mite as the vector supported Slykhuis' findings. The two principal tests utilized to determine if the mite was the vector were sap transmission and trials with nonviruliferous mites (Connin and Staples, 1957; Maramorosch, 1969). (See Appendix C.)

The economic importance of the mites was realized following Slykhuis' announcement. Studies were then initiated to determine the behavior of *Aceria tulipae* on wheat plants. In 1954, Kantack and Knutson found that the mites congregated on the bases of the leaf sheaths and in the pocket formed by the ligula. *Aceria tulipae* were also found on green seeds and various leaf areas of wheat. The mites live on immature wheat and disperse to other hosts as the wheat crop matures (Connin and Staples, 1957; del Rosario and Sill, 1965; Nault and Styer, 1969).

## Host Symptoms of Mite Feeding

Depending upon the susceptibility of the host plant to the mite, the size of the mite population and the presence of disease, varying symptoms are produced in response to mite feeding. Leaf rolling is the most obvious and visible symptom of mite feeding, but other symptoms include beards of wheat heads trapped by the rolled leaves and varying degrees of leaf chlorosis (Gibson and Painter, 1957; Kansas Field Crop

Insect Control Recommendations, 1981). When high mite populations are present in conjunction with a disease or other stress, the host plant often dies (Uyemoto and Ferguson, 1980).

The leaf rolling symptom is caused when the leaf section where *A. tulipae* is feeding is pushed upward. As the leaf unrolls from the center, a small spot remains curled where the mites are feeding. The mites do not cause the leaf to curl, but rather, prevent it from unrolling (Somsen and Sill, 1970). High mite populations can cause such severe leaf rolling that the leaves resemble garlic leaves (Slykhuis, 1955).

Plant factors which affect the amount of leaf rolling exhibited include:

1. the age of the leaf; more mature leaves are tougher and resist rolling.
2. the maturity of the plant; prestooling plants are most susceptible.
3. the condition of the plant in general; weak or diseased plants are more susceptible to leaf roll (Slykhuis, 1955).

# Chapter 6

# CONTROL

Control measures can be divided into three types; pesticidal, genetic, and cultural control. Traditional rules for control of virus diseases includes:

> "1. Elimination of the source of virus infection.
> 2. Avoiding the vectors.
> 3. Direct attack on the vectors.
> 4. Breeding resistant varieties of crops.
> 5. Cure of virus-infected plants.
> 6. Special methods of propogation."
> (Smith, 1968:145.)

Of this list, 1, 3, and 4 are utilized in the control of WSM. The methods of control will be discussed in ascending order of the amount of control provided.

## Direct Attack on the Vectors

Direct attack on the vector, *Aceria tulipae*, is accomplished with the use of pesticides. In Kansas, this has been an ineffective control measure (Kansas Field Crop Insect Control Recommendation, 1981; Kantack and Knutson, 1958). Since *A. tulipae* finds shelter within the curled

leaves, ligule pocket and leaf sheaths of their hosts, the mites are rarely exposed to sprayed on, direct-contact pesticides. The effectiveness of direct contact miticides is also limited by mite movement. As the season progresses and the plants grow, the mite colonies continually move to feed upon the newest plant tissues. This movement removes the mites from contact with the chemically treated plant surfaces (Kantack and Knutson, 1958).

Another factor limiting the amount of control is the washing action of rain which removes the chemical from the plant surfaces (Kantack and Knutson, 1958). This decreases the amount of time during which the mites can come into contact with the pesticide.

Kantack and Knutson (1958) tested 30 chemicals for miticidal effectiveness and found dieldrin and parathion to be the most effective of the chemicals, but far from satisfactory. In some cases, the mite population of treated plants was higher than the population upon untreated plants.

Systemic pesticides can control the mite population, but have several drawbacks. Most importantly, the use of systemics is too expensive to be feasible. Additional costs would include fees for trained personnel to scout for the microscopic vector, for justification of chemical use, and aerial application. A final drawback is that the mite transmits the virus before it is killed by the pesticide and thus provides inoculum for mites arriving after the breakdown of the pesticide.

## Breeding Resistant Varieties of Crops

Genetic control of wheat streak mosaic by using resistant or immune cultivars of wheat, has been relatively unproductive. It is suspected that both mite resistance and WSMV resistance are carried either on the

the same gene or on closely linked genes (Martin et al., 1976).

Thus far, no wheat cultivar grown in Kansas is resistant to wheat streak mosaic virus or its vector. The moderate tolerance exhibited by Scout derived cultivars like Eagle and Sage is broken down with the occurrence of high Fall temperatures such as existed during the growth of the 1980 wheat crop (Martin et al., 1976; Willis, 1981).

In spite of their shortcomings, mosaic tolerant cultivars have been credited with reducing losses in Kansas (Harris and Maramorosch, 1980). These cultivars have been developed gradually and new ones are constantly being tested (Somsen and Sill, 1970). Although immunity and high degrees of resistance have as yet been unattainable, new chromosome substitution lines appear promising as sources of resistance to both the vector and virus (Harris and Maramorosch, 1980). Presently recommended wheat cultivars for high risk areas are: Scout, Triumph, Bison, Kiowa, Concho, Rodco, Aztec, and Avoca (Sebesta and Bellingham, 1963; Somsen and Sill, 1970).

## Elimination of the Sources of Virus Infection

The most practical and effective measures of control of wheat streak mosaic are basic cultural practices such as plowing or deep disking, weed control, and date of planting. Because the vector, *Aceria tulipae*, and virus must have a continual succession of hosts, any disruption of more than six days in the succession of hosts will cause a reduction in the incidence of WSM.

With the knowledge that WSMV breaks down rapidly when tissues decompose, the grower may choose to plow under severely infected fields to destroy the virus. Mite populations are severely reduced when the leaves

are buried to a depth of one inch. Only a trace of the mite infestation survives burial at deeper depths (Brewer and Harrison, 1973; Slykhuis, 1955). Mites on leaves which are buried less than one inch deep or left on the surface can survive long enough to attack a wheat crop within six days of the tillage (Corbett and Sisler, 1964).

Mature and dead (field dried) plants are not acceptable hosts to either the vector or virus. Therefore, plowing after the crop reaches maturity, or has been harvested, is unimportant in the control of WSM as such plant residue does not serve as an infection source. However, the presence of large amounts of volunteer wheat may require plowing.

## Weed Control and Date of Planting

Volunteer wheat is of major importance in the survival of the virus and mite vector. Because of this, the date of planting may be shifted depending upon the length of time between elimination of the weed and crop emergence. Volunteer wheat should be destroyed and the seeded area kept clean for a minimum of six days prior to crop emergence, since the vector survives only for six days without a host plant (Corbett and Sisler, 1964; Maramorosch, 1969; Slykhuis, 1955).

The date of planting may also be affected by other factors. In areas where both Spring and Winter wheat are grown, Winter wheat should not be planted until at least six days after the Spring wheat has been harvested (Corbett and Sisler, 1964; Slykhuis, 1955). This provides the break necessary to reduce mite populations.

Late planting is also recommended to reduce the time period the virus is allowed to multiply within the plant before cold weather arrives (Niblett et al., 1974). The recommended period for planting wheat in

Southwest Kansas is September 25 through October 5. The effectiveness of late planting is dependent upon the temperatures occurring from October through November (Lengkeek, 1979). The Fall of 1980 and subsequent 1981 epidemic demonstrated the effect of warm weather in the early Winter, as the extremely warm weather extended the multiplication period of the mite and the virus.

Plants are more susceptible to mites and virus if they are under stress. Therefore, the practices of adequate fertilization and moisture conservation are recommended since the plants produced are more vigorous and better able to withstand an infection (Niblett et al., 1974).

# Chapter 7

# CONCLUSIONS

## Future Implications

Wheat streak mosaic has been found in many places around the world and has the potential of destroying a major portion of the world's wheat crop.

The virus and vector move from their overwintering wheat host onto several other crops. With alternative hosts available to support the survival and multiplication of both the mite and the virus, epidemics on wheat become a greater threat.

The disease may become economically destructive in the production of alternative host crops. Berger et al. (1981) stated that with the discovery of WSMV on wildrice in Canada and Minnesota, though the infection was not widespread, greater crop losses may occur in those areas in the future.

In Kansas, wet weather following the 1981 harvest has provided ideal conditions for abundant volunteer wheat. This could mean a disaster for the 1982 wheat crop if volunteer wheat is not controlled (Willis, 1981). Even then, alternative hosts may enable large populations of mites, from the 1981 epidemic, to survive with subsequent infection of the 1982 wheat crop.

Successful methods of control must be developed if significant crop

losses from wheat streak mosaic virus are to be prevented. The fact that WSMV may become important in other crops increases the necessity of developing successful control methods.

## GLOSSARY

Anaerobic -- without free oxygen.

Arthropod -- invertebrate animals with an exoskeleton and jointed appendages including insects, spiders, and crustaceans.

Chelicera -- an anterior pair of appendages, e.g. in spiders are specialized as fangs.

Chlorosis -- "fading of green plant color to light green or yellow" (Wiese, 1977, p. 97).

Dicotyledonous -- the group of plants having two seed leaves, e.g. soybeans, alfalfa.

Dioecious -- male reproductive organs are in separate individuals than female organs.

Immune -- "not affected by or responsive to disease" (Wiese, 1977, p. 99).

Inoculum -- "pathogen or its parts brought into contact with a host" (Wiese, 1977, p. 99).

Ligule -- a thin appendage of the foliar leaves.

Morphology -- "the form and structure of an organism or any of its parts" (Webster's New Collegiate Dictionary, 1976, p. 749).

Necrosis (necrotic) -- death.

Negatively phototrophic -- movement away from a light stimulus.

Nonviruliferous -- free of virus particles.

Pathogen -- "agent that causes disease" (Wiese, 1977, p. 100).

Perennials -- "persisting for more than two years or growing seasons" (Wiese, 1977, p. 100).

Positively phototrophic -- growth towards a light stimulus.

Resistance -- "property of hosts that prevents or impedes disease development" (Wiese, 1977, p. 100).

RNA -- "any of various nucleic acids containing rebose and uracil as structural components and are associated with control of cellular chemical activities" (Webster's New Collegiate Dictionary, 1976, p. 1,000).

Serology -- "a science dealing with serums and especially their reactions and properties (Webster's New Collegiate Dictionary, 1976, p. 1,059).

Stylet -- "a relatively rigid elongated appendage (as a piercing mouthpart) of an animal" (Webster's New Collegiate Dictionary, 1976, p. 1,157).

Susceptible -- "lacking resistance; prone to infection" (Wiese, 1977, p. 101).

Tolerant -- "sustaining disease without serious damage or yield loss" (Wiese, 1977, p. 101).

Transmission -- "spread, of virus or other pathogen, from plant to plant" (Wiese, 1977, p. 101).

Vector -- agent that transmits inoculum.

Virion -- "complete virus particle" (Wiese, 1977, p. 101).

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Table 1

COMPILATION OF WHEAT STREAK MOSAIC HOST STUDY RESULTS

BY CROP SUSCEPTIBILITY TO *Aceria tulipae* AND VIRUS

| Crop | Susceptibility to Mite | Susceptibility to Virus |
|---|---|---|
| Proso Millet | -- | S-Somsen & Sill (1970) |
| | Good | S-Lengkeek (1979) |
| Corn | Poor - Fair | S-Somsen & Sill (1970) |
| | | S-Harris & Maramorosch (1980) |
| | | S-Finley (1957) |
| | Poor - Fair | S-Lengkeek (1979) |
| Sorghum | -- | I-Somsen & Sill (1970) |
| | Poor - Good | I-Lengkeek (1979) |
| | * | I-Borgman (1959) |
| Rye | -- | S-Somsen & Sill (1970) |
| | Poor | R-Lengkeek (1979) |
| Barley | -- | S-Somsen & Sill (1970) |
| | S | S-Harris & Maramorosch (1980) |
| | NS - Poor | R-Lengkeek (1979) |
| Oats | -- | S-Somsen & Sill (1970) |
| | NS | R-Lengkeek (1979) |

S - Susceptible I - Immune to virus

R - Resistant NS - Nonsusceptible to mite

Poor-Fair-Good are subjective host ratings given by some authors.

* temporary host to mites up to 26 days.

Table 2

COMPILATION OF YIELD LOSSES FROM WHEAT

STREAK MOSAIC ON WHEAT IN CERTAIN YEARS IN KANSAS

| YEAR | AUTHOR | BUSHEL LOSS | % CROP INFECTION | COST |
|---|---|---|---|---|
| 1949 | Hansing et al. (1950) | 15,500,000 | 7% | $ 30,000,000 |
| 1951 | Willis (1981) | 6,000,000 | -- | 12,780,000* |
| 1952 | Willis (1981) | 6,000,000 | -- | 12,840,000* |
| 1954 | Willis (1981) | 6,000,000 | -- | 13,080,000* |
| 1959 | Willis (1981) | 33,708,000 | -- | 60,000,240* |
| | Finley (1957) | 46,670,000 | 20% | 83,072,600* |
| 1962 | Willis (1981) | 4,699,000 | -- | 9,679,940* |
| 1972 | Willis (1981) | 15,000,000 | -- | 25,200,000* |
| 1974 | Niblett et al. | -- | 1% | 750,000 |
| 1977 | Sim (1978) | -- | 1% | -- |
| 1978 | Sim (1978) | 11,175,500 | 3.5% | 32,297,195* |
| 1979 | Sim & Willis (1979) | 1,926,006 | 0.5% | 7,164,742* |
| 1980 | Sim & Willis (1980) | 1,224,400 | 0.3% | 4,713,940* |
| 1981 | Sim & Willis (1981)<br>Willis (1981) | 21,350,000 | 7% | 78,995,000** |

* Cost based on year-end price averages as given by the State Crop Reporting Service.

** Cost based on preliminary average for 1981.

Table 3

WHEAT VARIETAL YIELD REDUCTIONS IN 1974

BY NIBLETT ET AL.

| | % Yield Reduction |
|---|---|
| Bison | 20.2 |
| Centurk | 20.5 |
| Eagle | 6.4 |
| Parker | 15.5 |
| Triumph | 11.4 |

Table 4

1981 TOLERANCE RATING OF WHEAT VARIETIES

BY WILLIS

| VARIETY | DEGREE OF TOLERANCE |
|---|---|
| Triumph | Moderate |
| Triumph 64 | Moderate |
| Eagle* | Moderate |
| Sage | Slight** |
| Cloud | Slight** |
| Scout* | Slight** |
| Trisonmay | Slight** |

* The Scout-type of resistance as expressed in Eagle was of little value in the 1981 epidemic. Joe (T. J.) Martin, Charles Niblett and their coworkers documented the breakdown of this resistance with high Fall temperatures (Willis, 1981).

** Small amount of tolerance.

PLATE I

Diagram of Young Adult *Eriophyes tulipae* from Harris and Maramorosch (1980), pg 359

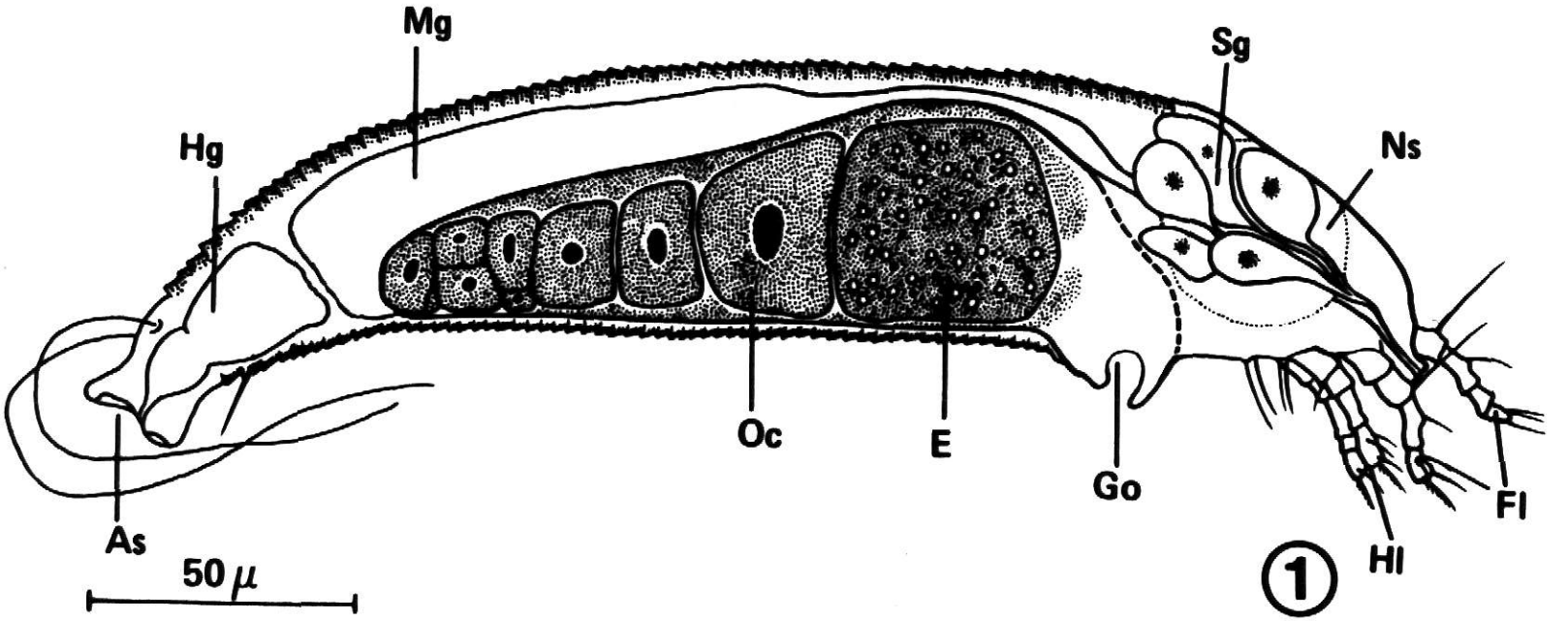
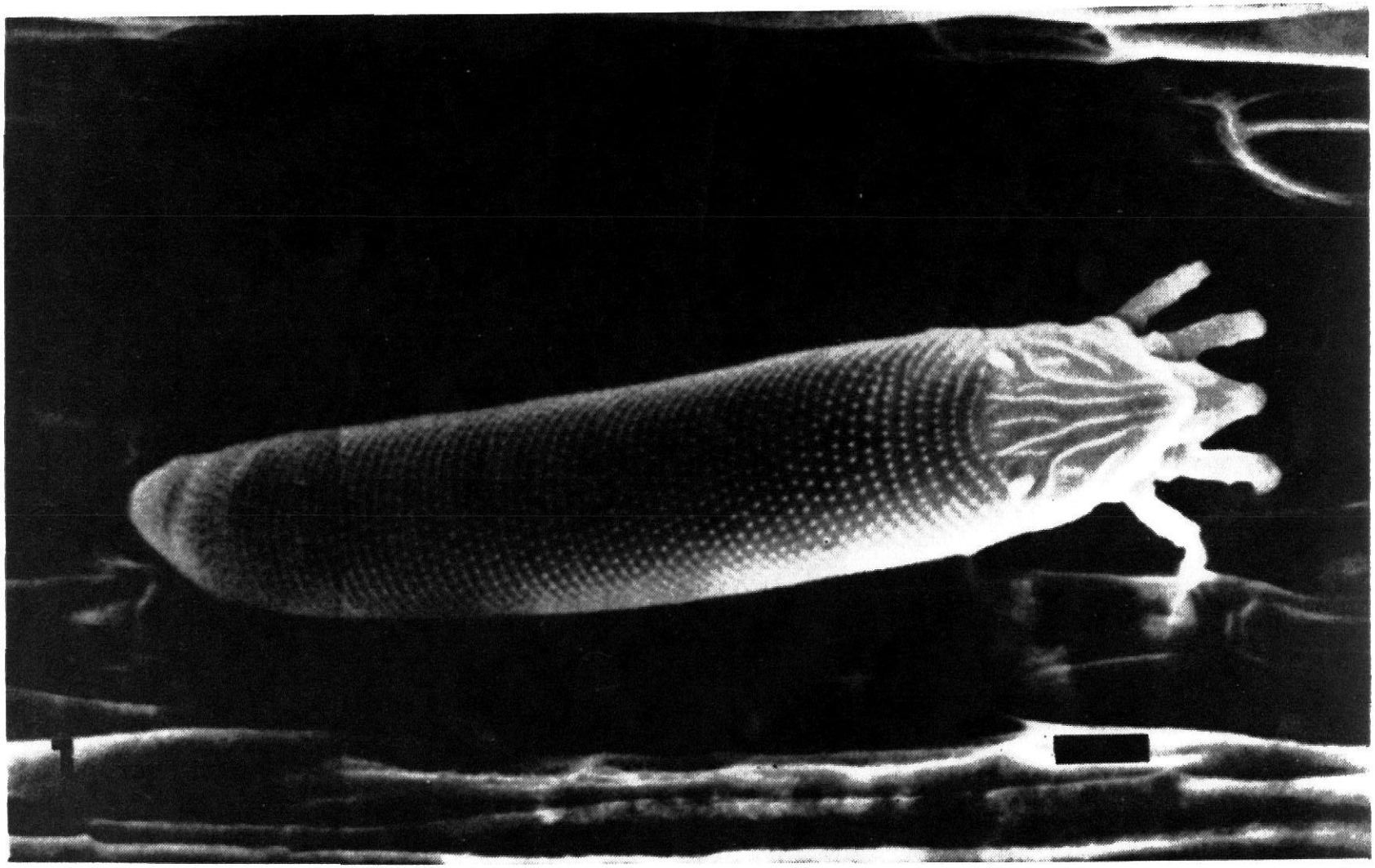



**FIG. 1.** Diagram of a young adult *Eriophyes tulipae* showing main anatomical features. As, anal sucker; E, egg; Fl, forelegs; Go, genital opening; Hg, hindgut; Hl, hindlegs, Mg, midgut; Ns neurosynganglion; Oc, oocyte; Sg, salivary glands.

PLATE I

PLATE II

*Aceria tulipae* (Keifer) (Acarina: *Eriophyidae*) on *Lolium* spp. in Wales from Chamberlain and Evans, Plant Pathology, 29(2):Plate IV, 1980.



1. Scanning electron micrograph of *Aceria tulipae* on leaf of *Lolium perenne*. Bar = 25 μm.

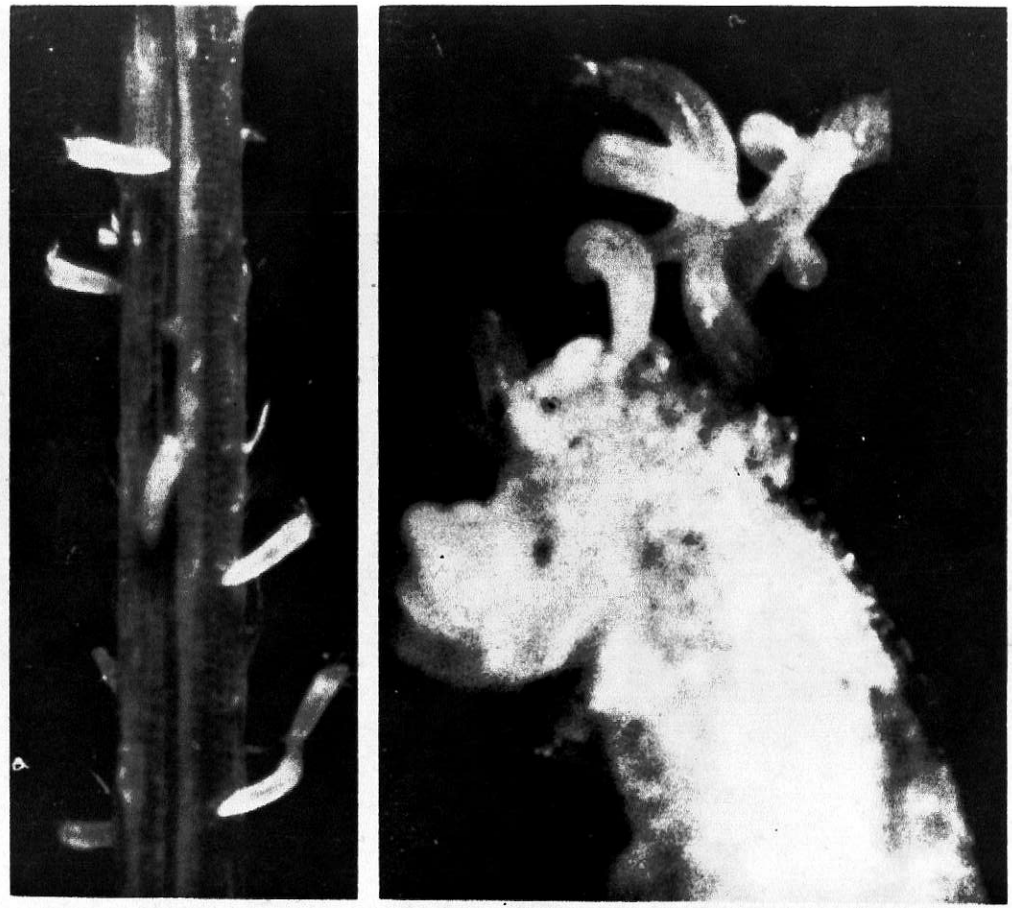
PLATE III

A. Mite Feeding Symptoms from Nault (1970), pg. 27

B. Pre-dispersal Behavior from Nault (1970), pg. 27

**Fig. 30.—Beards trapped by curling of leaves as the result of work of wheat curl mites, which carry wheat-streak mosaic. This same type of injury, including the rolling of leaves, also may be caused by hail or green bug. Uninjured head at left.**

A.



**Wheat curl mites exhibiting their pre-dispersal behavior by standing on anal sucker on a drying wheat leaf. The photographs are at two different magnifications—actual length of the mite is only .008 inch.**

B.

PLATE III

# APPENDIX A

Viral Characteristics:

The following characteristics of viruses which separate them from all other agents are quoted from Lwoff and Tournier (1966).

"1. Virons possess only one type of nuclic acid, either deoxyoribonucleic acid (DNA) or rubonucleic acid (RNA); other agents possess both types.

2. Virons are reproduced from their sole nucleic acid, whereas other agents are reproduced from the integrated sum of their constituents.

3. Virons are unable to undergo binnary fission.

4. Absence in the viruses of the genetic information for the synthesis of the Lipman System, the system responsible for the production of energy with high potential.

5. Viruses make use of ribosomes of their host cells, this is defined as absolute parasitism."

# APPENDIX B

## Hindgut Virus Accumulation in Mite:

Maramorosch (1969) believed the inability of the adult to acquire the virus if it did not feed until after reaching maturity, was due to the apparent degeneration of the connection between the midgut and hindgut (Maramorosch, 1969). Unless the particles were acquired prior to maturity, they would not be capable of reaching the hindgut from where they are assumed to be excreted (Maramorosch, 1969).

Authors who support the theory that the particles are introduced from the salivary gland through feeding activity disagree with this explanation. However, in the literature reviewed, these other authors did not set forth an alternate theory which would explain why particles are not picked up after reaching maturity.

# APPENDIX C

## Nonviruliferous Mite Trials

A. Transmittance Tests

1. *Aceria tulipae* eggs, which are incapable of carrying wheat streak mosaic virus, are hatched on healthy plants. The new mites are nonviruliferous.
2. The nonviruliferous mites are tranferred to diseased plants to feed and thereby injest the inoculum.
3. After feeding on the diseased plants for more than 15 minutes, the mites are then transferred to healthy plants to allow possible transmittance of wheat streak mosaic virus.
4. Development of disease symptoms on the healthy plants from step 3, indicates that the mite has transmitted the virus (Connin and Staples, 1957; Maramorosch, 1969).

B. Host Symptom Tests

Nonviruliferous mites are allowed to feed on healthy plants to determine the symptoms of mite feeding activity, e.g. leaf rolling.

The mites are not allowed to feed on diseased plants and are, therefore, incapable of injesting or transmitting wheat streak mosaic virus (Connin and Staples, 1957; Maramorosch, 1969).

These tests are also used for different diseases and their vectors.

# A REVIEW OF WHEAT STREAK MOSAIC

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## ABSTRACT

Wheat streak mosaic is a virus disease spread by an Eriophyid mite which can cause severe losses of wheat when conditions are suitable. In the typical Kansas year, control of volunteer wheat will significantly reduce or remove the threat of wheat streak mosaic virus. However, an atypical year with warm, extended Fall and Spring seasons, allows the mite to multiply rapidly and spread the disease throughout the area, as in the 1981 epidemic. The 1981 epidemic demonstrated the need for more extensive control measures.

Available literature is summarized to provide the layman with an understanding of the factors related to the occurrence of wheat streak mosaic and why present-day control measures are limited. The discussion of the disease is divided into the epidemiology of wheat streak mosaic, the virus, vector, control measures, and the future implications.