KERNEL RED STREAK ON INBRED AND HYBRID CORN (ZEA MAYS L.) INFECTED WITH WHEAT CURL MITES (ACERIA TULIPAE K.)

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
HABIBOLLAH FAKHRAI
1968

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By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop Science

1968

To my father, Mr. Mahmud Fakhrai,

and my mother, Mrs. Gohar Fakhrai (Ghotb),

for their sincere and dedicated support

all through my life.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. E. C. Rossman, for his guidance in the study and in the preparation of this manuscript.

Thanks are especially due to Dr. C. E. Cress, for his critical appraisal and help in the analyses of the data, Drs. J. Bath and E. Saari, for their help in procedures, and to Drs. C. M. Harrison and H. Slatis, for their critical review of the manuscript. Some financial support from DeKalb Agricultural Association, DeKalb, Illinois, is acknowledged.

Thanks are also due to my wife, Farideh, for help and patience throughout the course of this study.

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INTRODUCTION

Kernel red streak (KRS) was first noticed on corn in southern Michigan, northern Ohio, and northern Indiana in 1963. The infected area increased during 1964 in the three states, and into Ontario, Canada. Extensive KRS developed in Illinois in 1966. Pennsylvania also reported KRS on corn in 1966. KRS has been reported in Bulgaria, France, Romania, and Yugoslavia (11).

Longitudinal streaks of red color in the pericarp are the main visible symptoms of Kernel Red Streak. The red color does not extend into the endosperm tissue. The streaks usually spread upward from the tip end of the kernel. With heavy infection, the streaks coalesce and a major portion of the kernel becomes solid red to purple in color.

According to federal grain standards, corn may be graded "mixed" and discounted when 5% or more of the kernels in a sample are red colored. A kernel is not counted as red unless 50% or more of the kernel is red colored. Discounts for KRS have been applied rather sporadically over the area and are not being applied currently. There have been no reports of adverse effects on feeding quality of KRS infected grain (21).

The causal agent remained obscure until a virus, Ohio 3A strain of Wheat Streak Mosaic Viris (WSMV), was isolated from KRS infected plants by Williams et al. (26) in 1965. Two years later, Nault et al. (11) showed that the insect vector of WSMV, the microscopic wheat curl mite (Aceria tulipae Keifer), was the primary causal agent and not WSMV per se. KRS developed on the kernal pericarp as a result of feeding by virus-free mites as well as by viruliferous mites. They suggested that a phytotoxin, possibly in the saliva, produced the red streaking. Plants infected with WSMV appeared to be better hosts for the mite, but plants inoculated with WSMV alone did not develop KRS.

WSMV and its vector have been present for many years in the Great Plains wheat area where the virus is a major disease of wheat. KRS has not been found on corn in this area. WSMV has been a relatively minor disease of wheat in the Michigan, Ohio, and Indiana area where KRS suddenly appeared on corn in 1963.

Explanations are not clear why KRS does not develop on corn in the Great Plains and does develop in certain areas of the Midwest. Possibly a different strain, a "corn strain" of wheat curl mite, has evolved in the Midwest.

Rossman (16) reported that a higher degree of KRS developed when yields were low and moisture stress existed during the season.

KRS was also present on grain from high yielding fields but usually less intense.

Does KRS affect yield? Attempts to produce comparable plots with and without KRS under field conditions had been unsuccessful until the causal agent was clearly determined in 1966. The application of systemic insecticides for mite control appeared to be a possibility for a set of KRS-free plots to compare with plots artificially infested with mites to produce KRS.

Objectives were to study the effects of three treatments (virus free mites, WSMV infected mites, and control with systemic insecticides) on development of KRS and on yield. Twenty-four genotypes (13 inbreds and 11 hybrids including red and white cob materials previously rated relatively susceptible and resistant to either WSMV or KRS) were used in this study.

REVIEW OF LITERATURE

Williams *et al.* (26) obtained a virus, Ohio 3A, from KRS infected plants and suspected that it was the causal agent. The mosaic pattern on the leaves was described as a series of dots and dashes. This virus has since been shown (10, 11) to be a strain of WSMV.

Paliwal *et al.* (14) in 1966 reported that there was no indication that WSMV produced KRS. They were unable to isolate WSMV from locations where KRS occurred in Ontario, Canada.

Nault *et al.* (11) found that the WSMV insect vector *Aceria tulipae* K. (wheat curl mite) and not WSMV was the primary cause of KRS. They found a high correlation between the presence of mites and KRS. Inoculation with virus free mites as well as with viruliferous mites produced KRS. They concluded that presence of the virus was not essential for development of KRS, but might make the plant more attractive to the mite. Since wheat curl mites are known to have toxigenic effects on several hosts, it seemed possible that KRS might be due to phytotoxin secreted by the feeding mite.

Everly (2) also found that mite infection was associated with KRS but some samples with KRS had no mites and some samples with no KRS had mites.

WSMV has rarely occurred with any significant effect or with any degree of regularity on corn. Its potential danger has been noted (4) but the limited population of susceptible corn could not itself cause an epidemic of WSMV on corn. McKinney (9) inoculated 8 varieties of dent corn and 13 varieties of sweet corn with Wheat Streak Mosaic Virus in the greenhouse. The percentage of plants with mosaic symptoms ranged from 0-68 percent. Plants with severe mosaic were stunted but none were killed. Five varieties (1 dent and 4 sweet) developed no mosaic. No data were reported for grain appearance.

W. B. Allington (University of Nebraska, personal communication) observed that the pollinator parent of a commercial corn hybrid in the North Platte area of Nebraska was highly susceptible to WSMV. In several seed fields the pollinator parent was dead soon after pollination while the seed parent in the same field was unaffected. No KRS was ever observed on corn in Nebraska, where WSMV is common on wheat. Other states in the Great Plains wheat area where WSMV has been a problem for many years report no KRS on corn.

King and Sill (7) estimated a 20% loss in wheat yield in Kansas due to WSMV. Presence of WSMV in corn and wheat has been found to create greater susceptibility of the host to fungal crown and root rots (22).

The susceptible host range of WSMV includes several species of wheat and oats, some varieties of corn, barley, rye, and wild grasses such as Aegilops cylindrica Host, Bromus japonicus Thumb, and others (3). Sill and Connin (17) reported that WSMV overwinters on wheat. Susceptible summer grasses are distributed widely enough to serve as interim hosts between wheat harvest and planting, and furnish a source of inoculation for each new wheat crop.

Slykhuis (19) reported effective control of WSMV and wheat spot mosaic by eliminating immature volunteer wheat before winter wheat was planted. The continuous sequence of wheat necessary to perpetuate the disease was interrupted. Staples and Allington (22) stated that destruction of native grasses was not important or practical for control of WSMV.

Slykhuis (18) was the first to report the wheat curl mite (Aceria tulipae K.) as the insect vector for WSMV. The virus could be transmitted by all forms of the insect except the egg. Connin and Staples (1) found that the mite occasionally clings to other insects and escapes detection.

Staples and Allington (22) reported that annual host grasses provided a source of the virus and were suitable hosts for the mite.

They found that wind was the main method of mite dispersal and some mite migration occurred throughout the year. Volunteer wheat germinating after harvest also served as an interim host for the virus and the mite.

Orlob (12) reported that most annual grasses were either immune to WSMV or did not support mites but certain grasses such as *Setaria viridis* served as interim hosts for the virus or vector. In the fall, viruliferous mites from grasses such as *Setaria viridis* were transported to winter wheat and introduced the virus. He stated that since *Aceria tulipae* K. from these grasses do not adapt readily to wheat, wheat adapted mites would be needed to spread the virus within the field. Intra-field spread of WSMV from infected source plants was confined to short distances. It appeared that viruliferous mites were blown into most fields without causing extensive intra-field spread.

McKinney *et al.* (10) stated that wheat and susceptible corn varieties could be year-round hosts for both virus and mites throughout the Corn Belt and the eastern Great Plains.

Keifer (6) first described *Aceria tulipae* and gave average measurement of 250 microns in length and 75 microns in width for the adult.

Mites thrived best in the greenhouse under high humidity, but flooding for 24 hours or more, was detrimental and eventually lethal (15). Phototropic response of mites was negative.

Egg to egg cycle at 75-78 F was found to be 8-10 days (15, 22). Mites reproduced parthenogenetically. At least 12 eggs were produced by each female.

Leaves of young wheat plants infested with mites became rolled, parallel to the veins, from one edge to the other (22). Mites progressed from older leaves to new leaves.

On corn, mites gain access to the kernels through the silk and tip of the ear (11). L. R. Nault (unpublished) reported that mites appeared on corn early (plants 4-6 inches tall) in the season and continued to increase during the season in 1967 in Ohio.

None of 30 different insecticides applied in greenhouses and in the field in the spring gave initial or residual control of mites (5). Leaf rolling and penetration beneath leaf sheaths gave protection to the mites. No control of WSMV was obtained when seeds were treated with Am. Cyanamid 12008, 12009.

Kernel Red Streak is most common on yellow dent corn and least common on white corn (11). It has been noted on sweet, pop, and flint corns.

Rating of inbred lines of corn by Rossman (16) and others showed that white cob inbreds tended to be relatively free of KRS compared to red cob material. Some streaking was noted on a few white cob inbreds. Likewise, some red cob lines were relatively free of streaking.

Rossman (16) found consistent differences in amount and intensity of streaking among commercial hybrids in overstate corn performance trials in Michigan. None were completely free of KRS. All were red cob hybrids.

Unpublished tests by Rossman have shown that no infectious principal was carried by seed with KRS. Heavily streaked seed from Michigan was planted in the Florida winter corn breeding-genetics research nursery in 1963 and 1964. No KRS developed anywhere in the Florida nursery.

KRS occurred more commonly at the ear tips, particularly if husks were loose and kernels exposed, but also appeared randomly on the ear (11). KRS increased in amount and intensity progressively from slightly before denting until heavy killing frost in the fall (16).

MATERIALS AND METHODS

Three treatments were applied to 24 corn varieties (13 inbreds and 11 hybrids) in a split plot design with four replications on the Michigan State University Crop Science Department Experimental Farm near East Lansing in 1967. The three treatments were:

T_1 Control plots were treated with systemic insecticides in an attempt to keep natural infestation of mites at a minimum. Two applications of NIA 10242 (2, 3-dihydro-2-2-dimethyl-7-benzofuranyl methyl carbamate) were applied to the soil, 14 days and 75 days after planting. Three applications of dimethoate-2E were applied to silks on August 15, September 1, and September 15.

T_2 Viruliferous mites, reared on Monon wheat plants inoculated with isolate 931 of WSMV by Dr. E. G. Saari (Department of Plant Pathology, Michigan State University) were placed into the ears soon after silking.

T_3 Virus-free mites were reared on uninoculated wheat plants and transferred to corn ears soon after silking.

For both treatments (T_2 and T_3), wheat leaves were inspected for presence of mites and then cut into small sections containing about ten mites. The small pieces of leaves were inserted into the tip of each ear between the silk and husk. Hybrids were infested with viruliferous mites and with virus-free mites on August 2 and 3; inbreds were infested August 14 and 15.

The corn was hand planted May 13. Excess seed was planted and the plants were thinned later to a population of about 25,900 per acre. Plots were one row 14 feet long with 25 plants. All plots received 300 pounds 10-20-20 fertilizer in the row and 120 pounds nitrogen (anhydrous ammonia) sidedressed in mid-June for a total of 130-60-60 pounds of N-P_2O_5-K_{20} per acre. No "effective" rainfall (.4" or more) occurred from July 20 to August 19 and some moisture stress developed on the plants during this period.

The 13 inbreds included seven lines with red cob (MS80, W9R (22), MS140, MS142 Rf, W153R, Oh51A, and MS153 Rf) and six with white cob (B8, MS141, MS142 Rf, MS57, SD10, and MS153 Rf). Two inbreds, MS142 Rf and MS153 Rf, were represented by both a red and a white cob segregate obtained from a backcross program that converted these two lines to pollen restorers. The 11 hybrids consisted of two double cross hybrids, Michigan 270 and Michigan 400, and nine single cross hybrids. MS141 x B8 and

MS1334 x Oh43 involve only white cob inbreds in their pedigree. MS140 x B8, MS142 x B8, MS142 x MS141 and MS140 x MS141 are crosses of red cob x white cob inbreds. MS142 x MS140 and Michigan 402-2X (W64A x WF9) (MS92 x MS93) are red cob x red cob crosses. DeKalb XL15 is closed pedigree single cross with red cob. Michigan 270 (MS1334 x B8) (W10 x MS206) is a cross of a white cob single cross with a red cob single cross. Michigan 400 (W64A x Oh43) (W10 x MS206) has one white cob inbred, Oh43, in its pedigree.

One ear from each plot was harvested September 30-October 6 for mite count and KRS rating. The procedure developed by Dr. James Bath, Department of Entomology, Michigan State University, was used for mite counts. The ear with husk attached was cut, sprayed with chloroform in a jar and washed with 190 proof grain alcohol. Three U. S. standard sieves, Numbers 10, 70 and 325 (with openings of 2 mm, 125 microns and 40 microns, respectively), were used to strain off the mites in the alcohol solution. Mites collected inside of the No. 325 screen were washed off with alcohol into a vial with a volume of 1640 drops.

A three drop sample on a concave slide was taken for the mite count using a 40 times magnitude binocular.

The degree of color intensity (scored as 0, 0.5, 1.5, 2.0, 2.5 or 3.0 with 0 being no color and 3.0 representing heaviest coloration) was determined for each one ear per plot sample.

Two types of correlations of mite counts with KRS ratings were calculated:

1. simple correlation over all treatments and varieties, and
2. within correlation eliminating treatment within variety effects.

The final harvest was taken on October 15 when 10 plants per plot were harvested for yield determination and KRS rating. Plot weights were converted to bushels per acre at 15.5% moisture. The 10 ears were shelled after drying. A bulk sample of 100 kernels was counted to obtain the percentage of kernels showing KRS. The kernels showing KRS in the sample were rated for intensity using scores of 0 (no color) to 8 (heavily colored).

An index (Z) for KRS was calculated for each plot using the formula:

$$Z = \log_{10} \left(\frac{X^2 \cdot Y}{100}\right) + 1$$

where X is the color intensity score and Y = percent kernels with KRS. This index is somewhat arbitrary, but is used in an effort to obtain a measure of total severity of KRS infestation.

RESULTS AND DISCUSSION

Mite Counts and KRS Scores, September 30-October 6

One ear per plot was harvested during September 30-October 6, 1967, for wheat curl mite counts (Table 3) and scored (0-3) for KRS (Table 2). Analyses of variance are presented in Table 1.

Screened mites from each ear were washed into a vial containing about 1640 drops. A three drop sample (one 547^{th}) was taken from the vial for the mite count. Multiplying the count by 547 gives an estimate of the mite population per ear.

The effect of treatment and varieties and their interaction were highly significant for both mite counts and KRS scores (Table 1). The control treatment (T_1 = systemic insecticides) had significantly lower mite populations (averaging 2.32) and significantly lower KRS scores (averaging .89) than ears of either of the other two treatments which were manually infested with mites. Ears infested with viruliferous mites (T_2) had an average mite count of 14.73 and an average KRS score of 1.70. Infestation with virus-free (T_3) averaged 16.14 on mite counts and 1.73 on KRS scores. The differences

Table 1.--Analyses of variance for Kernel Red Streak scores and mite counts sampled September 30-October 6, 1967.

Source of variation	Degrees of freedom	Mite counts			Kernel Red Streak scores		
		Sum of squares	Mean square	F	Sum of squares	Mean square	F
Total	287	26648.90			278.10		
Replication	3	42.50	14.20		1.80	0.60	
Treatments	2	11093.70	5546.90	973.10[a]	44.20	22.10	71.29[a]
Error A	6	34.00	5.70		1.90	0.30	
Varieties	23	4109.70	178.70	4.74[a]	157.90	6.90	28.62[a]
Varieties x treatments	46	3367.00	77.50	2.06[a]	23.40	0.50	2.13[a]
Error B	207	7802.00	37.70		49.00	0.24	

[a]Significant at .01 level of probability.

Table 2.--Mean KRS scores for 13 corn inbreds and 11 hybrids with three treatments sampled September 30-October 6, 1967.

Variety	Cob color[a]	Treatment[b]			Comparisons	
		T_1	T_2	T_3	T_1 vs T_2 & T_3	T_2 vs T_3
Inbreds:						
MS80	Rc	0.00	1.75	1.00	**	*
W9R(22)	Rc	1.13	3.00	2.75	**	ns
B8	Wc	0.38	0.63	0.38	ns	ns
MS141	Wc	0.00	0.00	0.00	ns	ns
MS140	Rc	2.13	2.88	2.88	*	ns
MS142 Rf	Rc	1.13	2.75	2.50	**	ns
MS142 Rf	Wc	0.13	0.13	0.13	ns	ns
W153R	Rc	0.75	2.00	2.50	**	ns
Oh51A	Rc	1.75	2.88	2.75	**	ns
MS57	Wc	1.13	1.13	1.13	ns	ns
SD10	Wc	2.00	2.00	1.88	ns	ns
MS153 Rf	Wc	0.13	0.63	0.63	ns	ns
MS153 Rf	Rc	0.63	2.00	2.38	**	ns
Mean of 13 inbreds:		0.87	1.70	1.61	*	ns
Mean of 6 white cob inbreds:		0.63	0.80	0.69	ns	ns
Mean of 7 red cob inbreds:		1.08	2.47	2.39	**	ns
Hybrids:						
MS140 x B8	Rc = Rc x Wc	1.25	2.13	2.13	**	ns
MS141 x B8	Wc = Wc x Wc	0.25	0.75	0.88	ns	ns
MS142 x B8	Rc = Rc x Wc	0.50	1.50	1.25	**	ns
MS141 x MS140	Rc = Wc x Rc	1.00	1.50	2.13	**	ns
MS142 x MS140	Rc = Rc x Rc	1.50	2.88	2.88	**	ns
MS142 x MS141	Rc = Rc x Wc	0.50	1.75	1.38	**	ns
MS1334 x Oh43	Wc = Wc x Wc	0.75	1.00	1.25	ns	ns
Mich. 270 (MS1334 x B8) x (W10 x MS206)	Rc = (Wc x Wc) x (Rc x Rc)	1.00	1.75	2.50	**	*
Mich. 402-2X (W64A x WF9) x (MS92 x MS93)	Rc = (Rc x Rc) x (Rc x Rc)	1.13	1.63	2.13	*	ns
Mich. 400 (W64A x Oh43) x (W10 x MS206)	Rc = (Rc x Wc) x (Rc x Rc)	0.63	1.63	1.50	**	ns
DeKalb XL15 closed pedigree	Rc	1.63	2.50	2.75	**	ns
Mean of 11 hybrids:		0.92	1.73	1.90	**	ns
Mean of 2 white cob hybrids:		0.50	0.88	1.07	ns	ns
Mean of 9 red cob hybrids:		1.02	1.92	2.10	**	ns
Mean of all 24 varieties:		0.89	1.70	1.73	**	ns
Mean of 8 white cob varieties:		0.60	0.82	0.79	ns	ns
Mean of 16 red cob varieties:		1.50	2.16	2.24	*	ns
Least Significant Difference:		0.80	0.64	0.62		

[a]Rc = red cob; Wc = white cob.

[b]T_1 = control with systemic insecticide; T_2 = manual infestation of ear with viruliferous mites; T_3 = manual infestation of ear with virus-free mites.

** = significant at 0.01 level of probability.
* = significant at 0.05 level of probability.
ns = not significant.

Table 3. -- Mean mite counts of 3 drop samples for 13 inbreds and 11 hybrids with three treatments sampled September 30-October 6, 1967.

Variety	Cob color[a]	Treatment[b]			Comparisons	
		T_1	T_2	T_3	T_1 vs T_2 & T_3	T_2 vs T_3
Inbreds:						
MS80	Rc	3.00	18.50	13.50	**	ns
W9R(22)	Rc	1.50	31.00	25.25	**	ns
B8	Wc	2.00	4.00	5.25	ns	ns
MS141	Wc	2.00	12.75	20.25	**	ns
MS140	Rc	4.25	8.50	24.50	**	*
MS142 Rf	Rc	1.50	18.75	20.50	**	ns
MS142 Rf	Wc	2.25	15.25	7.75	*	ns
W153R	Rc	2.75	18.25	11.75	**	ns
Oh51A	Rc	6.25	19.75	23.75	**	ns
MS57	Wc	1.75	23.25	19.50	**	ns
SD10	Wc	2.00	5.25	15.25	*	*
MS153 Rf	Wc	1.25	12.25	6.75	*	ns
MS153 Rf	Rc	1.50	10.25	16.50	**	ns
Mean of 13 inbreds:		2.46	15.21	16.20	**	ns
Mean of 6 white cob inbreds:		1.86	12.13	12.46	**	ns
Mean of 7 red cob inbreds:		2.96	17.86	19.54	**	ns
Hybrids:						
MS140 x B8	Rc = Rc x Wc	0.50	11.50	17.00	**	ns
MS141 x B8	Wc = Wc x Wc	1.25	3.50	10.50	ns	ns
MS142 x B8	Rc = Rc x Rc	2.25	9.25	11.00	*	ns
MS141 x MS140	Rc = Wc x Rc	1.50	11.25	13.50	**	ns
MS142 x MS140	Rc = Rc x Rc	3.75	26.50	25.50	**	ns
MS142 x MS141	Rc = Rc x Wc	2.75	16.00	15.75	**	ns
MS1334 x Oh43	Wc = Wc x Wc	1.00	18.75	16.50	**	ns
Mich. 270						
(MS1334 x B8) x (W10 x MS206)	Rc = (Wc x Wc) x (Rc x Rc)	1.75	9.00	14.75	**	ns
Mich. 402-2X						
(W64A x WF9) x (MS92 x MS93)	Rc = (Rc x Rc) x (Rc x Rc)	3.50	9.25	20.75	**	*
Mich. 400						
(W64A x Oh43) x (W10 x MS206)	Rc = (Rc x Wc) x (Rc x Rc)	3.00	19.50	16.75	**	ns
DeKalb XL15 closed pedigree	Rc	2.50	21.25	14.75	**	ns
Mean of 11 hybrids:		2.16	14.16	16.00	**	ns
Mean of 2 white cob hybrids:		2.12	11.13	13.50	**	ns
Mean of 9 red cob hybrids:		2.38	14.83	16.67	**	ns
Mean of all 24 varieties:		2.32	14.73	16.14	**	ns
Mean of 8 white cob varieties:		1.93	11.88	12.72	**	ns
Mean of 16 red cob varieties:		2.63	16.16	17.93	**	ns
Least Significant Difference:		2.60	12.00	8.44		

[a]Rc = red cob; Wc = white cob.

[b]T_1 = control with systemic insecticide; T_2 = manual infestation of ear with viruliferous mites; T_3 = manual infestation of ear with virus-free mites.

** = significant at 0.01 level of probability.
 * = significant at 0.05 level of probability.
ns = not significant.

Multiply mite counts by 547 for the estimated mite population per ear.

between ears infested with viruliferous mites and those infested with virus-free mites (T_2 vs T_3) were not significant for either mite counts or KRS scores. Ears that were manually infested with mites (T_2 and T_3) averaged 6 to 7 times more mites and about twice as high on KRS scores.

Effectiveness of the systemic insecticides (NIA 10242 = 2, 3, dihydro-2-2-dimethyl-7-benzofuranyl methyl carbamate applied to the soil and dimethoate 2-E applied to the silk) for wheat curl mite cannot be judged here since there was no treatment where insecticides were not used. However, insecticides did not provide complete control of mites since control ears averaged about 1369 mites (2.32 x 547) per ear.

The control treatments (T_1) ranged from a low of 0.5 mites per sample for MS140 x B8 to a high of 6.25 for Oh51A. When manually infested, MS140 x B8 had 11.50 (T_2) and 17.00 (T_3) mites per sample, representing a 23- and 34-fold increase over the control. For all varieties there were 6.6 and 7.5 times more mites for the two manually infested treatments (T_2 and T_3) than for the control treatment.

Manual infestation of ears with viruliferous mites did not increase the KRS scores compared with ears infested with virus-free mites. There were only three instances (MS140, SD10 and hybrid

Michigan 402-2X) of a significant difference between these two treatments (T_2 vs T_3) in mite counts and two cases of significant difference for KRS (inbred MS80 and hybrid Michigan 270).

No visual symptoms of Wheat Streak Mosaic Virus (WSMV) were detected on any of the plots during the growing season. The viruliferous mites (T_2) were reared on Monon wheat plants inoculated with WSMV, and, as such, were assumed to be carrying the virus. Virus transmission tests (corn to Monon wheat) were made for all varieties in T_2. None were positive, indicating that the mites reared on Monon wheat infected with WSMV did not transmit the virus to the corn. Inbred Oh51A had been rated highly susceptible to WSMV according to unpublished tests conducted by L. E. Williams in Ohio. Virus transmission tests (corn to Monon wheat) for Oh51A were negative.

There was a natural population of mites in the area as evidenced by the mite counts obtained from the control treatments. Wheat research plots were adjacent to the corn plots and could have been the source of the natural infestation. Some of the mites present on the manually infested plots (T_2 and T_3) were probably from the natural population in the area. It is not known whether the natural population of mites were viruliferous or virus-free. Nault et al.

(11) found that mites from only two of 68 ears collected from fields in Ohio transmitted WSMV.

Infestation with viruliferous mites did not increase KRS over that obtained with virus-free mites. Since there was no evidence of WSMV from visual symptoms on corn or from corn to Monon wheat transmission tests for T_2 and T_3, it appears that the development of KRS was largely independent of the WSMV. Controlled experiments by Nault et al. (11) have demonstrated that KRS developed on ears infested with virus-free mites. Paliwal et al. (14) found that KRS developed on plants that had no WSMV and also on plants that had WSMV, based on transmission tests. They also isolated WSMV from plants that had no KRS and concluded that WSMV was not the cause of KRS.

The within correlation (removing treatment within variety effects) of mite counts with KRS scores was .72 which was highly significant (Table 8). This relationship indicates that the higher KRS scores were generally obtained on ears possessing higher mite populations. Nault et al. (11) obtained significant correlations ranging from .47 to .67 for mite counts with KRS incidence. The correlation of mite counts with KRS scores was .64, very highly significant, for 16 red cob varieties but was not significant, .16, for 8 white cob varieties. White cob varieties showed relatively little KRS even though there were appreciable mite populations on them.

Red cob inbreds and hybrids averaged higher in mite counts and in KRS scores than white cob inbreds and hybrids for all three treatments (Tables 2 and 3). KRS scores averaged two to three times higher for red cob inbreds and hybrid groups than for white cob groups. Mite counts averaged only 1.38 times higher for red cob than for white cob, while KRS scores averaged 2.47 times for red cob varieties.

White cob inbred MS141 showed no KRS in either treatment yet it had about average mite counts. The white cob version of MS142 Rf had the next lowest KRS score (.13) in all 3 treatments and also had mite counts as high as several inbreds and hybrids (both white and red cob) with relatively high KRS scores. These two exceptions to the .72 correlation of mite counts with KRS scores indicate that a low KRS score was not due to absence of mites. This is illustrated further by the correlation between mite counts and KRS scores for the eight white cob inbreds and hybrids, .16 (Table 8), which is not significant. Nault et al. (11) postulated that a phytotoxin, probably a salivary component, may be secreted by the mite and result in the red streaking on the pericarp. The KRS "resistant" white cob lines may lack a pigment precursor in the pericarp that, when present in KRS "susceptible" varieties, reacts with the excreted salivary phytotoxin of the mite to produce red streaking on the pericarp.

The average mite counts and the average KRS scores for the 13 inbreds were similar to the average for 11 hybrids. There was no consistent indication that the inbreds as a group were any more or less attractive to mites than the hybrids.

Yield, % KRS, KRS Color Intensity Score, and KRS Index, October 15

Ten plants in each plot were harvested for yield on October 15. No mite counts were made at this final harvest. The percentage of kernels with KRS and the intensity of the color (scores: 0 = no KRS color to 8 = pericarp almost completely red colored) were determined using a 100 kernel sample of the shelled grain from each plot. A KRS index was calculated using the formula:

$$\text{Index KRS} = Z = \log\left(\frac{X^2 \cdot Y}{100} + 1\right)$$

where X is the KRS color intensity score and Y is the percent KRS.

Analyses of variance for percent KRS (means in Table 5), color intensity scores (means in Table 6), and KRS index (means in Table 7) are presented in Table 4. There were highly significant differences due to treatments and varieties for all three measurements

Table 4. -- Analyses of variance for percent KRS, color intensity scores, and KRS index sampled October 15, 1967.

Source of variation	Degrees of freedom	% KRS			KRS color intensity score			KRS index		
		Sum of squares	Mean square	F	Sum of squares	Mean square	F	Sum of squares	Mean square	F
Total	287	334341.7			1122.9			86.57		
Replication	3	2696.1	898.7		4.3	1.4		.47	0.16	
Treatment	2	85148.1	42574.0	59.6[a]	206.9	103.5	246.3[a]	21.90	10.90	266.58[a]
Error A	6	4287.7	714.6		2.6	0.4		0.25	0.04	
Variety	23	181149.0	7876.0	60.1[a]	705.9	30.7	69.8[a]	48.16	2.10	63.33[a]
Variety x treatment	46	33928.1	737.6	5.6[a]	112.1	2.4	5.6[a]	9.10	0.20	5.98[a]
Error B	207	27132.7	131.1		91.2	0.4		6.80	0.03	

[a]Significant at .001 level of probability.

of KRS. The interactions, treatment x varieties, were also highly significant. But the mean squares were much smaller than the main effect mean square. White cob inbreds and hybrids, as a group, were not affected by the mite treatments while red cob varieties were significantly affected.

Average KRS percentages for all varieties were 28.0% for the control treatment with systemic insecticides (T_1), 65.4% when infested with viruliferous mites (T_2) and 65.0% when infested with virus-free mites (T_3). Color intensity scores for these treatments were 1.57, 3.33 and 3.41 respectively. There were no significant differences, for any of the 24 varieties, between infestation with viruliferous mites and with virus-free mites (T_2 vs T_3) for color intensity score. For KRS percentage, there were only three cases where there was a significant difference between T_2 and T_3. MS80 had significantly higher KRS percentage in T_2 and MS153 Rf Rc and MS141 x MS140 had higher percentage in T_3.

T_2 and T_3 had similar effects, no significant differences between them, for most measurements of KRS. There was no evidence of WSMV on corn in T_2 infested with mites reared on WSMV infected Monon wheat plants. Both treatments involved manual infestation of ears with mites and had significantly higher KRS measurements and higher mite counts than the control, T_1. Except for most white cob genotypes, all comparisons of T1 with T_2 and T_3 were significant.

In general, white cob inbreds showed no significant increase in KRS with added mite populations, T_1 vs T_2 and T_3. The only exception was inbred B8 which did show a significant increase in KRS color intensity score. The two white cob single-cross hybrids, MS141 x B8 and MS1334 x Oh43, had significantly higher percentage of KRS for T_2 and T_3 than for T_1, but no significant increase in color intensity scores or KRS indexes.

Six white cob inbreds averaged 25.9, 28.6 and 32.5% KRS for the three treatments (T_1, T_2, T_3) compared to 37.7, 86.1 and 84.9% for the seven red cob inbreds (Table 5). Two white cob hybrids averaged 14.6, 41.3 and 37.9% KRS compared to 27.3, 79.1 and 77.3% for nine red cob hybrids, Table 5.

Color intensity scores averaged 0.8, 1.4 and 1.3 for six white cob inbreds and 2.0, 4.6 and 4.8 for the seven red cob inbreds, Table 6. Average scores for white cob hybrids were 1.3, 1.5 and 1.3, and 1.8, 4.1 and 4.2 for red cob hybrids.

KRS indexes averaged .20, .29 and .32 for white cob inbreds and .41, 1.24 and 1.27 for red cob inbreds, Table 7. Hybrids averaged .12, .31 and .21 for white cob and .30, 1.1 and 1.1 for red cob. The possible range of KRS index was 0-1.813; the actual range was 0-1.809.

Table 5. -- Mean percent KRS for 13 inbreds and 11 hybrids with three treatments sampled October 15.

Variety	Cob color[a]	Treatment[b]			Comparisons	
		T_1	T_2	T_3	T_1 vs T_2 & T_3	T_2 vs T_3
Inbreds:						
MS80	Rc	10.75	77.50	53.25	**	*
W9R(22)	Rc	63.00	98.75	99.00	**	ns
B8	Wc	00.00	12.50	6.00	ns	ns
MS141	Wc	00.00	00.00	1.25	ns	ns
MS140	Rc	33.00	87.50	80.75	**	ns
MS142 Rf	Rc	50.25	96.25	92.75	**	ns
MS142 Rf	Wc	00.00	00.00	00.00	ns	ns
W153R	Rc	38.75	86.50	90.25	**	ns
Oh51A	Rc	36.25	97.50	97.75	**	ns
MS57	Wc	63.75	57.25	66.00	ns	ns
SD10	Wc	78.00	71.00	87.25	ns	ns
MS153 Rf	Wc	13.50	30.75	34.25	*	ns
MS153 Rf	Rc	27.00	58.50	80.50	**	*
Mean of 13 inbreds:		31.87	59.54	60.69	**	ns
Mean of 6 white cob inbreds:		25.88	28.58	32.46	ns	ns
Mean of 7 red cob inbreds:		37.71	86.07	84.89	**	ns
Hybrids:						
MS140 x B8	Rc = Rc x Wc	28.25	81.75	66.75	**	ns
MS141 x B8	Wc = Wc x Wc	7.25	15.75	21.00	ns	ns
MS142 x B8	Rc = Rc x Wc	15.75	77.25	77.75	**	ns
MS141 x MS140	Rc - Wc x Rc	17.75	59.00	78.75	**	*
MS142 x MS140	Rc = Rc x Rc	30.75	81.00	85.75	**	ns
MS142 x MS141	Rc = Rc x Wc	9.75	69.00	67.25	**	ns
MS1334 x Oh43	Wc = Wc x Wc	22.00	66.75	54.75	**	ns
Mich. 270 (MS1334 x B8) x (W10 x MS206)	Rc = (Wc x Wc) x (Rc x Rc)	33.50	81.50	79.00	**	ns
Mich. 402-2X (W64A x WF9) x (MS92 x MS93)	Rc = (Rc x Rc) x (Rc x Rc)	31.50	94.75	83.00	**	ns
Mich. 400 (W64A x Oh43) x (W10 x MS206)	Rc = (Rc x Wc) x (Rc x Rc)	26.50	75.50	66.00	**	ns
DeKalb XL15 closed pedigree	Rc	52.00	92.50	91.50	**	ns
Mean of 11 hybrids:		25.00	72.25	70.14	**	ns
Mean of 2 white cob hybrids:		14.63	41.25	37.87	**	ns
Mean of 9 red cob hybrids:		27.30	79.14	77.33	**	ns
Mean of all 24 varieties:		28.00	65.36	65.02	**	ns
Mean of 8 white cob varieties:		23.68	31.75	33.81	ns	ns
Mean of 16 red cob varieties:		31.85	82.16	80.61	**	ns
Least Significant Difference:		19.00	15.60	13.50		

[a]Rc = red cob; Wc = white cob.

[b]T_1 = control with systemic insecticide; T_2 = manual infestation of ear with viruliferous mites; T_3 = manual infestation of ear with virus-free mites.

** = significant at 0.01 level of probability.
* = significant at 0.05 level of probability.
ns = not significant.

Table 6. -- Mean KRS color intensity scores (0-8)[c] for 13 inbreds and 11 hybrids with three treatments sampled October 15.

Variety	Cob color[a]	Treatment[b]			Comparisons	
		T_1	T_2	T_3	T_1 vs T_2 & T_3	T_2 vs T_3
Inbreds:						
MS80	Rc	0.75	3.00	2.25	**	ns
W9R(22)	Rc	2.75	7.25	8.00	**	ns
B8	Wc	0.00	2.00	0.75	**	ns
MS141	Wc	0.00	0.00	0.25	ns	ns
MS140	Rc	2.75	4.75	5.25	**	ns
MS142 Rf	Rc	2.25	5.25	5.25	**	ns
MS142 Rf	Wc	0.00	0.00	0.00	ns	ns
W153R	Rc	2.00	4.75	4.75	**	ns
Oh51A	Rc	1.75	4.50	4.75	**	ns
MS57	Wc	2.00	2.75	2.50	ns	ns
SD10	Wc	2.00	2.25	2.75	ns	ns
MS153 Rf	Wc	0.75	1.25	1.75	ns	ns
MS153 Rf	Rc	1.75	2.75	3.50	**	ns
Mean of 13 inbreds:		1.44	3.12	3.21	**	ns
Mean of 6 white cob inbreds:		0.79	1.38	1.33	ns	ns
Mean of 7 red cob inbreds:		2.00	4.61	4.82	**	ns
Hybrids:						
MS140 x B8	Rc = Rc x Wc	2.00	3.75	3.75	**	ns
MS141 x B8	Wc = Wc x Wc	0.75	1.00	1.00	ns	ns
MS142 x B8	Rc = Rc x Wc	1.50	3.00	3.00	**	ns
MS141 x MS140	Rc = Wc x Rc	1.25	2.75	2.75	**	ns
MS142 x MS140	Rc = Rc x Rc	2.00	5.00	5.50	**	ns
MS142 x MS141	Rc = Rc x Wc	0.75	2.50	2.50	**	ns
MS1334 x Oh43	Wc = Wc x Wc	1.75	2.00	1.50	ns	ns
Mich. 270 (MS1334 x B8) x (W10 x MS206)	Rc = (Wc x Wc) x (Rc x Rc)	1.75	3.75	3.75	**	ns
Mich. 402-2X (W64A x WF9) x (MS92 x MS93)	Rc = (Rc x Rc) x (Rc x Rc)	1.75	4.75	5.00	**	ns
Mich. 400 (W64A x Oh43) x (W10 x MS206)	Rc = (Rc x Wc) x (Rc x Rc)	2.00	3.75	3.50	**	ns
DeKalb XL15 closed pedigree	Rc	3.50	7.25	7.75	**	ns
Mean of 11 hybrids:		1.73	3.60	3.64	**	ns
Mean of 2 white cob hybrids:		1.25	1.50	1.25	ns	ns
Mean of 9 red cob hybrids:		1.83	4.06	4.16	**	ns
Mean of all 24 varieties:		1.57	3.33	3.41	**	ns
Mean of 8 white cob varieties:		0.91	1.41	1.31	ns	ns
Mean of 16 red cob varieties:		1.90	4.30	4.45	**	ns
Least Significant Difference:		1.03	0.84	0.94		

[a]Rc = red cob; Wc = white cob.

[b]T_1 = control with systemic insecticide; T_2 = manual infestation of ear with viruliferous mites; T_3 = manual infestation of ear with virus-free mites.

[c]Color intensity scores: 0 = no KRS color on pericarp; 8 = nearly solid KRS color on pericarp.

** = significant at 0.01 level of probability.
 * = significant at 0.05 level of probability.
ns = not significant.

Table 7. -- Mean KRS index[c] for 13 inbreds and 11 hybrids with three treatments sampled October 15.

Variety	Cob color[a]	Treatment[b]			Comparisons	
		T_1	T_2	T_3	T_1 vs T_2 & T_3	T_2 vs T_3
Inbreds:						
MS80	Rc	0.043	0.900	0.577	**	ns
W9r(22)	Rc	0.728	1.722	1.809	**	ns
B8	Wc	0.000	0.175	0.025	ns	ns
MS141	Wc	0.000	0.000	0.005	ns	ns
MS140	Rc	0.523	1.304	1.354	**	ns
MS142 Rf	Rc	0.549	1.429	1.413	**	ns
MS142 Rf	Wc	0.000	0.000	0.000	ns	ns
W153R	Rc	0.406	1.300	1.326	**	ns
Oh51A	Rc	0.344	1.312	1.352	**	ns
MS57	Wc	0.545	0.721	0.701	ns	ns
SD10	Wc	0.615	0.652	0.872	ns	ns
MS153 Rf	Wc	0.054	0.186	0.317	ns	ns
MS153 Rf	Rc	0.249	0.727	1.027	**	ns
Mean of 13 inbreds:		0.311	0.802	0.829	**	ns
Mean of 6 white cob inbreds:		0.202	0.289	0.320	ns	ns
Mean of 7 red cob inbreds:		0.405	1.242	1.265	**	ns
Hybrids:						
MS140 x B8	Rc = Rc x Wc	0.376	1.089	1.002	**	ns
MS141 x B8	Wc = Wc x Wc	0.030	0.063	0.081	ns	ns
MS142 x B8	Rc = Rc x Wc	0.169	0.883	0.901	**	ns
MS141 x MS140	Rc = Wc x Rc	0.121	0.706	0.834	**	ns
MS142 x MS140	Rc = Rc x Rc	0.328	1.310	1.426	**	ns
MS142 x MS141	Rc = Rc x Wc	0.039	0.716	0.708	**	ns
MS1334 x Oh43	Wc = Wc x Wc	0.204	0.564	0.342	*	ns
Mich. 270 (MS1334 x B8) x (W10 x MS206)	Rc = (Wc x Wc) x (Rc x Rc)	0.299	1.088	1.078	**	ns
Mich. 402-2XX (W64A x WF9) x (MS92 x MS93)	Rc = (Rc x Rc) x (Rc x Rc)	0.270	1.338	1.314	**	ns
Mich. 400 (W64A x Oh43) x (W10 x MS206)	Rc = (Rc x Wc) x (Rc x Rc)	0.332	1.060	0.939	**	ns
DeKalb XL15 closed pedigree	Rc	0.810	1.694	1.745	**	ns
Mean of 11 hybrids:		0.270	0.956	0.943	**	ns
Mean of 2 white cob hybrids:		0.117	0.314	0.214	ns	ns
Mean of 9 red cob hybrids:		0.304	1.098	1.105	**	ns
Mean of all 24 varieties:		0.292	0.873	0.873	**	ns
Mean of 8 white cob varieties:		0.181	0.295	0.294	ns	ns
Mean of 16 red cob varieties:		0.384	1.161	1.175	**	ns
Least Significant Difference:		0.580	0.320	0.460		

[a] Rc = red cob; Wc = white cob.

[b] T_1 = control with systemic insecticide; T_2 = manual infestation of ear with viruliferous mites; T_3 = manual infestation of ear with virus-free mites.

[c] KRS index = $\log\left(\frac{\text{KRS color intensity score x \%KRS}}{100} + 1\right)$. The possible range of KRS index = 0-1.813. The actual range = 0-1.809.

** = significant at 0.01 level of probability.
* = significant at 0.05 level of probability.
ns = not significant.

Except for T_1, hybrids averaged slightly higher than inbreds for all three KRS measurements but the differences between the two variety groups were relatively small.

Two nearly isogenic inbred comparisons of white vs red cob were available with MS142 Rf and MS153 Rf segregates. Five generations of backcrossing to the recurrent parent (red cob) and one generation of inbreeding to add the Rf (pollen restoring) gene had been involved. The difference between the white and red cob segregates of MS142 Rf were marked. White cob MS142 Rf had no KRS in any treatment while red cob MS142 Rf had 50.3, 96.3 and 92.8% KRS and scored 2.3, 5.3 and 5.3 in color intensity for the three treatments. Red cob MS153 Rf had twice as much KRS (27.0, 58.5 and 80.5% and color intensity scores of 1.8, 2.8 and 3.5 for the three treatments, respectively) as white cob MS153 Rf (13.5, 30.8 and 34.3% and scores of 0.8, 1.3 and 1.8). There were no consistent differences in mite populations, Table 3, for the white and red cob segregates of these two inbreds, MS142 Rf and MS153 Rf.

While most white cob varieties showed significantly less KRS than red cob materials, there were three exceptions. White cob inbreds, SD10 and MS57, and the hybrid MS1334 x Oh43 had relatively high KRS values.

KRS coloring on white cob varieties has been typically more purple than red. In the 1967-68 Florida winter corn breeding-genetics research nursery near Homestead, Florida, SD10 had 68% of the kernels showing a purple-red streaking on the pericarp with a color intensity score of 3.0 (personal communication, E. C. Rossman). The color pattern appeared identical to that designated as KRS in summer in Michigan during 1965-1967. None of the other inbreds and hybrids in the winter nursery showed any color streaking on the pericarp. A number of the inbreds and hybrids included in the study were also in the Florida nursery--B8, MS141, MS142 Rf (both red and white cob), W153R, Oh51A, MS153 Rf (red and white cob), MS142 x MS140, Michigan 270, Michigan 400, and Michigan 402. Several of these were among the most KRS susceptible varieties yet they showed no evidence of pericarp color in the Florida nursery. From these observations, it appears that the color streaking on SD10 which has been designated KRS may actually be due to some other conditions and deserves additional study.

Table 8 presents correlations among mite counts and four KRS measurements for all 24 varieties, the 16 red cob varieties, and the eight white cob varieties. Considering all 24 varieties and the 16 red cob varieties, the four correlations of mite counts with the four KRS measurements were highly significant, .52 to .72.

Table 8. -- Correlations between mite counts, percent KRS, KRS color intensity scores, and KRS index.

Characteristics correlated	r		
	For all 24 varieties	For 16 red cob inbreds and hybrids	For 8 white cob inbreds and hybrids
KRS scores Sept. 30-Oct. 6 and mite counts Sept. 30-Oct. 6	.53**	.64**	$.16^{ns}$
Removing effect of treatment within varieties	.72**		
KRS score Sept. 30-Oct. 6 and percent KRS Oct. 15	.78**	.69**	.80**
KRS score Sept. 30-Oct. 6 and KRS scores Oct. 15	.78**	.70**	.70**
KRS score Sept. 30-Oct. 6 and KRS index Oct. 15	.81**	.74**	.73**
Mite counts Sept. 30-Oct. 6 and percent KRS Oct. 15	.52**	.61**	.28*
Mite counts Sept. 30-Oct. 6 and KRS scores Oct. 15	.52**	.59**	$.25^{ns}$
Mite counts Sept. 30-Oct. 6 and KRS index Oct. 15	.56**	.63**	.34**
Percent KRS Oct. 15 and KRS score Oct. 15	.83**	.79**	.84**
Percent KRS Oct. 15 and KRS index Oct. 15	.92**	.92**	.94**
KRS score Oct. 15 and KRS index Oct. 15	.96**	.96**	.90**

** = significant at .01 level.
* = significant at .05 level.
ns = not significant.

These same correlations for the eight white cob varieties were lower, .16 to .34, and only two of the four were significant. Presence of mites and KRS development were much more closely associated for red cob than for white cob varieties.

Correlation among the four KRS measurements were all very highly significant indicating that classifications based on either KRS color intensity scores, percentage KRS, or a KRS index rated the varieties similarly.

Classification of the 24 varieties roughly into KRS susceptible, intermediate and resistant groups applying Tukey's method (23) to the KRS indexes, Table 9, showed the following in order of decreasing susceptibility within each group.

Susceptible		Intermediate		Resistant	
Inbreds:		Inbreds:		Inbreds:	
W9R(22)	(Rc)[1]	SD10	(Wc)	MS153 Rf	(Wc)
MS142 Rf	(Rc)	MS153 Rf	(Rc)	B8	(Wc)
MS140	(Rc)	MS57	(Wc)	MS141	(Wc)
W153R	(Rc)	MS80	(Rc)	MS142	(Wc)
Oh51A	(Rc)				
Hybrids:		Hybrids:		Hybrids:	
DeKalb XL15	(Rc)	MS142 x B8	(Rc)	MS141 x B8	(Wc)
MS142 x MS140	(Rc)	MS141 x MS140	(Rc)		
Mich. 402-2X	(Rc)	MS142 x MS140	(Rc)		
MS140 x B8	(Rc)	MS1334 x Oh43	(Wc)		
Mich. 270	(Rc)				
Mich. 400	(Rc)				

[1](Rc) = red cob; (Wc) = white cob.

Table 9. -- Classification of 24 corn varieties into KRS susceptible, intermediate and resistant groups based on Tukey's method applied to the KRS index.

Variety	Cob color[a]	KRS index value	Classification[b]	
Inbreds:				
W9R(22)	Rc	1.42		
MS142	Rc	1.13	a	Susceptible
MS140	Rc	1.06	a	Susceptible
W153R	Rc	1.01	a	Susceptible
Oh51A	Rc	1.00	a	Susceptible
SD10	Wc	0.71	b	Intermediate
MS153 Rf	Rc	0.67	b	Intermediate
MS57	Wc	0.66	b	Intermediate
MS80	Rc	0.50	b	Intermediate
MS153 Rf	Wc	0.19	f	Resistant
B8	Wc	0.07	f	Resistant
MS141	Wc	0.00	f	Resistant
MS142 Rf	Wc	0.00	f	Resistant
Hybrids:				
DeKalb XL15	Rc	1.42		
MS142 x MS140	Rc	1.02	a	Susceptible
Mich. 402-2X	Rc	0.97	a	Susceptible
MS140 x B8	Rc	0.82	a b	Susceptible
Mich. 270	Rc	0.82	a b	Susceptible
Mich. 400	Rc	0.77	a b c	Susceptible
MS142 x B8	Rc	0.65	b c d	Intermediate
MS141 x MS140	Rc	0.55	c d e	Intermediate
MS142 x MS141	Rc	0.49	d e	Intermediate
MS1334 x Oh43	Wc	0.37	e	Intermediate
MS141 x B8	Wc	0.06		Resistant

[a]Rc = red cob; Wc = white cob.

[b]Any two varieties connected by the same letter are statistically the same.

Four inbreds (MS153 Rf white cob segregate, B8, MS141 and MS142 Rf white cob segregate) and one hybrid, MS141 x B8, were classified as resistant. All were white cob entries. Eleven entries, all red cob, were classified as relatively susceptible. Eight entries, five red cob and three white cob, were rated intermediate in resistance.

Data from uniform KRS nurseries conducted in Michigan, Ohio, Indiana and Ontario, Canada, during 1966 and 1967 (mimeograph, Minutes of North Central Corn Breeding Committee, NCR-2, Feb., 1967, and March, 1968) showed that some red cob were as resistant as white cob inbreds. Red cob inbreds W9R(22) and MS80 were rated relatively resistant in the Univorm NCR-2 KRS nurseries. In the present study, W9R(22) was rated highly susceptible and MS80 rated intermediate. These two reversals indicate the possibility for genotype x environment interactions. However, rating of commercial hybrids in Michigan overstate corn trials in 1966 by Rossman (16) and the data in the two year Uniform KRS nursery report indicate fairly good agreement in rating of the same genotype in different environments.

White cob color is recessive to red cob color in corn. Crosses involving KRS resistant white cob lines (MS141 and B8) with KRS susceptible red cob lines (MS140 and MS142) indicated that the resistance associated with white cob was also recessive.

Does KRS affect the yield of corn? This has been one of the most frequently asked questions about KRS. Until the causal agent and its control were identified, there was no procedure to induce KRS at will on one set of plots and to keep another set free of KRS for yield determinations. One of the main objectives in this study was to produce KRS free corn using systemic insecticides to control wheat curl mites and compare the yields with plots manually infested with mites.

The systemic insecticides used here (NIA 10242 = 2, 3-dihydro-2-2-dimethyl-7-benzofuranyl methyl carbamate applied to the soil and dimethoate 2-E applied to the silk) did not provide complete control of mites (T_1). There was an average of about 1369 mites per ear for all varieties. The two mite infested treatments (T_2 and T_3) averaged 8,057 and 8,829 mites per ear (Table 3), six to seven times more mites per ear.

An analysis of variance for yield (Table 10) showed no significant difference in yield due to mite populations. Six- to sevenfold increases in mite population per ear did not result in any significant difference in yield. There were significant differences among varieties. The interaction, variety x treatment, was not significant.

The 13 inbreds averaged 58.0, 57.6 and 54.5 bushels while the 11 hybrids averaged 95.0, 122.3 and 114.8 bushels per acre for

Table 10.--Analysis of variance for yield sampled October 15, 1967.

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Total	287	465103.3		
Replication	3	74605.1	24868.4	
Treatment	2	3531.2	1765.6	1.60[ns]
Error A	6	6629.2	1104.9	
Variety	23	268356.2	11667.7	25.96[a]
Variety x treatment	46	18960.0	412.2	0.92[ns]
Error B	207	93021.7	449.4	

a = significant at .001 level.
ns = not significant.

$$CV(a) = \frac{1104.9}{81.4} \times 100 = 41\%$$

$$CV(b) = \frac{449.4}{81.4} \times 100 = 26\%$$

T_1, T_2 and T_3 treatments, respectively, Table 11. The differences for T_2 and T_3 compared with the control, T_1, 27.3 and 19.8 bushels, were not statistically significant. In 9 out of the 11 hybrid comparisons, T_1 vs T_2 and T_3, the control plot (T_1) yields were arithmetically lower than T_2 and T_3. In two cases these differences were statistically significant (MS140 x B8 and MS142 x MS140, both red

Table 11.--Mean yields bushel per acre for 13 inbreds and 11 hybrids with three treatments, October 15. Plant population = 25,900 per acre.

Variety	Cob color[a]	Treatment[b]			Comparisons	
		T_1	T_2	T_3	T_1 vs T_2 & T_3	T_2 vs T_3
Inbreds:						
MS80	Rc	42.3	45.7	47.4	ns	ns
W9R(22)	Rc	33.1	40.2	32.1	ns	ns
B8	Wc	49.7	50.9	45.9	ns	ns
MS141	Wc	40.4	34.4	34.4	ns	ns
MS140	Rc	61.4	77.0	65.9	ns	ns
MS142 Rf	Rc	78.2	72.3	67.7	ns	ns
MS142 Rf	Wc	68.2	74.9	86.4	ns	ns
W153R	Rc	78.7	73.7	60.5	ns	ns
Oh51A	Rc	62.6	64.3	57.0	ns	ns
MS57	Wc	74.8	58.5	61.7	ns	ns
SD10	Wc	41.5	50.4	42.1	ns	ns
MS153 Rf	Wc	44.2	54.1	39.0	ns	ns
MS153 Rf	Rc	78.8	51.8	68.4	ns	ns
Mean of 13 inbreds:		58.0	57.6	54.5	ns	ns
Mean of 6 white cob inbreds:		53.1	53.9	53.1	ns	ns
Mean of 7 red cob inbreds:		62.2	60.7	57.0	ns	ns
Hybrids:						
MS140 x B8	Rc = Rc x Wc	90.1	124.4	115.4	*	ns
MS141 x B8	Wc = Wc x Wc	108.9	109.6	103.8	ns	ns
MS142 x B8	Rc = Rc x Wc	115.7	104.7	130.8	ns	ns
MS141 x MS140	Rc = Wc x Rc	102.7	125.9	120.6	ns	ns
MS142 x MS140	Rc = Rc x Rc	70.5	117.8	115.0	*	ns
MS142 x MS141	Rc = Rc x Wc	103.8	115.0	103.8	ns	ns
MS1334 x Oh43	Wc = Wc x Wc	119.6	134.5	120.9	ns	ns
Mich. 270 (MS1334 x B8) x (W10 x MS206)	Rc = (Wc x Wc) x (Rc x Rc)	98.6	121.1	95.8	ns	ns
Mich. 402-2X (W64A x WF9) x (MS92 x MS93)	Rc = (Rc x Rc) x (Rc x Rc)	112.8	127.7	131.4	ns	ns
Mich. 400 (W64A x Oh43) x (W10 x MS206)	Rc = (Rc x Wc) x (Rc x Rc)	96.3	125.8	110.7	ns	ns
DeKalb XL15 closed pedigree	Rc	115.9	138.8	114.7	ns	ns
Mean of 11 hybrids:		95.0	122.3	114.8	ns	ns
Mean of 2 white cob hybrids:		114.3	122.1	122.4	ns	ns
Mean of 9 red cob hybrids:		100.8	122.4	115.4	ns	ns
Mean of all 24 varieties:		75.0	87.2	82.1	ns	ns
Mean of 8 white cob varieties:		68.4	70.9	67.9	ns	ns
Mean of 16 red cob varieties:		83.9	95.4	89.8	ns	ns

[a]Rc = red cob; Wc = white cob.

[b]T_1 = control with systemic insecticide; T_2 = manual infestation of ear with viruliferous mites; T_3 = manual infestation of ear with virus-free mites.

* = significant at 0.05 level of probability.
ns = not significant.

cob). For all 24 varieties the average yield per acre was 75.0, 87.2 and 82.1 bushels in three treatments. But these differences were not significant.

No biological explanation for the lower arithmetic yield for hybrids on control plots (T_1) is apparent. The difference was apparently due to experimental variability in yield. Or maybe it was due to injurious effect of the insecticides on the plants.

SUMMARY

Three treatments (T_1, T_2, T_3) were applied to 24 varieties (13 inbreds and 11 hybrids) of corn in the field. T_1 = systemic insecticides (NIA 10242 = 2, 3-dihydro-2-2-dimethyl-7-benzofuranyl methyl carbamate applied to the soil and dimethoate 2-E applied to the silk) for wheat curl mite, *Aceria tulipae*, control. T_2 = manual infestation of ears with mites reared on Monon wheat infected with wheat streak mosaic virus, WSMV. T_3 = manual infestation of ears with mites reared on virus-free Monon wheat.

The objectives were: (1) to determine the effect of mite populations and WSMV on development of Kernel Red Streak, KRS; (2) to determine the relative importance of varieties, including white cob vs red cob varieties, on KRS development; and (3) to determine the effect of KRS on yield of corn.

Mite counts per ear averaged 1, 369, 8, 057, and 8, 829 for the three treatments, respectively.

Manual infestation of ears with mites reared on Monon wheat plants (T_2) inoculated with wheat streak mosaic virus (WSMV) did not increase the incidence of KRS over that obtained with manual

infestation with mites reared on virus-free Monon wheat plants (T_3). Both manual mite infestation treatments did significantly increase the KRS scores compared to the control treated with systemic insecticides (T_1). The insecticide treatment did not provide complete mite control.

There were significant differences among varieties for mite counts and for KRS measurements. The average correlation (removing treatment within variety effects) of mite counts with KRS scores was .72, very highly significant. KRS was generally more prevalent on ears with higher mite populations.

There was no evidence based on symptoms on corn plants or from virus transmission tests (corn to Monon wheat) that the virus reared mited transmitted WSMV to corn in T_2.

White cob inbreds and hybrids averaged 38.5% lower in mite counts and in KRS measurements than red cob inbreds and hybrids for all three treatments. KRS scores averaged two to three times higher for red cob inbred and hybrid groups than for white cob groups.

Two nearly isogenic white cob segregates of MS142 Rf and MS153 Rf had significantly less KRS than the red cob segregates of these two lines. There was no consistent difference in the mite populations for the white and red cob versions.

The five varieties (four inbreds and one hybrid) classified as KRS resistant were all white cob entries. The KRS resistance associated with white cob color appeared to be recessive.

There was no consistent indication that the inbreds were any more or less attractive to mites than the hybrids.

Yields were not significantly different for the three mite treatments. Hybrids yields were arithmetically lower for the control treatment, T_1, but the difference (except for two of the varieties) was not statistically significant.

REFERENCES

1. Connin, R. V., and Staples, R. S. 1957. Role of various insects and mites in the transmission of wheat streak mosaic virus. Jour. of Econ. Ent. 50:168-170.

2. Everly, R. T. 1966. Preliminary report on KRS-wheat curl mite survey in Indiana in 1966. Purdue University, Lafayette, Indiana.

3. Holdeman, Q. L., and McCartney, W. O. 1965. Virus diseases of corn _Zea mays_ L. A plant disease detection aid. Bureau of Plant Pathology, State of California, Department of Agriculture, Sacramento, Cal. 95814.

4. How, Shao Chung. 1963. Wheat streak mosaic virus on corn in Nebraska. Phytopathology 53:279-280.

5. Kantack, E. J., and Nutson, H. 1958. Chemical control studies of the wheat curl mite. Jour. of Econ. Ent. 51:68-72.

6. Keifer, H. H. 1938. Eriophyid studies. California Department Agr. Bul. 27:181-206.

7. King, C. L., and Sill, W. H., Jr. 1959. Wheat streak mosaic epiphytotic in Kansas. Plant Disease Reporter 43:1256.

8. McKinney, H. H. 1949. Virus isolates from mosaic wheat in the hard red winter wheat area. Plant Disease Reporter 33:346-349.

9. __________. 1949. Test of varieties of wheat, barley, oats and corn for reaction to wheat streak mosaic virus. Plant Disease Reporter 33:359-369.

10. __________, Brakke, Myron K., Ball, Ellen M., and Staples, R. 1966. Wheat streak moxaic virus in the Ohio Valley. Plant Disease Reporter 50:951-953.

11. Nault, L. R., Brion, M. L., Williams, L. E., and Barry, B. D. 1967. Relation of the wheat curl mite to kernel red streak of corn. Phytopathology 57:986-989.

12. Orlob, G. B. 1966. Epidemiology of wheat streak mosaic virus in South Dakota 1962-1966: host range studies. Plant Disease Reporter 50:819-821.

13. __________. 1966. Epidemiology of wheat streak mosaic virus in South Dakota 1962-1966: virus spread. Plant Disease Reporter 50:917-920.

14. Paliwal, Y. C., Slykhuis, J. T., and Wall, R. E. 1966. Wheat streak mosaic virus in corn in Ontario. Canada Plant Disease Survey 46:8.

15. Rosaris, M. S. D., and Sill, W. H., Jr. 1958. A method of rearing large colonies of an Eriophyid mite, Aceria tulipae (Kief.), in pure culture from single egg or adults. Journ. of Econ. Ent. 51:303-306.

16. Rossman, E. C. 1967. Kernel red streak. Department of Crop Sci., Mich. State Univ., East Lansing, Mich., unpublished.

17. Sill, W. H., Jr., and Connin, R. V. 1953. Summary of the known host range of the wheat streak mosaic virus. The Kansas Academy of Sci. 56:411-417.

18. Slykhuis, J. T. 1956. Wheat spot mosaic, caused by a mite transmitted virus associated with wheat streak mosaic. Phytopathology 46:682-687.

19. __________. 1960. Current status of mite-transmitted plant virus. Proc. Ent. Soc. Ont. 90:22-29.

20. __________. 1961. Eriophyid mites in relation to the spread of grass virus in Ontario. Can. Jour. of Plant Science 41: 304-308.

21. Smith, N. A. 1966. Kernel red stripe of field corn. Michigan State University Cooperative Extension Service BBP66-1.

22. Staples, R., and Allington, W. B. 1956. Streak mosaic of wheat in Nebraska and its control. Univ. of Neb. Agr. Exp. Station Research Bul. 178:1-40.

23. Steel, R. G. D., and Torrie, J. H. 1960. Principles and procedures of statistics. McGraw-Hill, pp. 481.

24. Stoner, W. N. 1965. Some corn (maize) virus diseases in the United States. Plant Disease Reporter 49:918-922.

25. Wall, R. E., and Mortimore, C. G. 1965. Red striped pericarp of corn. Canada Plant Disease Survey 45:92.

26. Williams, L. E., Alexander, L. J., and Runnels, H. A. 1965. A virus isolated from red streak corn grain. Abs. Phytopathology 55:1083-1084.

27. ___________, Gordon, D. T., Nault, L. R., Alexander, L. J., Bradfute, O. E., and Findley, W. R. 1967. A virus of corn and small grains in Ohio and its relation to wheat streak mosaic virus. Plant Disease Reporter 51: 207-211.