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A MOSAIC DISEASE OF WINTER WHEAT AND WINTER RYE

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INTRODUCTION

This mosaic disease of winter wheat, referred to previously by the writer and his collaborators in published papers[1] dealing with wheat rosette, was first observed by the writer near Granite City, Ill., in 1919 while studying the rosette disease. At that time little attention was given to the foliage mottling which it manifests, because it occurred on varieties which did not develop the rosette condition. The following year, observations indicated that this foliage mottling bore some relation to the soil, and for this reason the disease was not seriously considered to be a true mosaic. Subsequent investigations, however, indicate that both this mottling and the rosette condition are manifestations of a transmissible mosaic disease, the virus of which is capable of existing for extended periods in certain soils.

DISTRIBUTION AND IMPORTANCE

Wheat mosaic has been found in Madison, Mason, Logan, and Cass Counties in Illinois and in La Porte and Porter Counties in Indiana. Rosette occurred in Sangamon County, Ill., and Tippecanoe County, Ind., in 1919, but since that time it has not been

[1] H. H. McKinney. Investigations of the rosette disease of wheat and its control. *In* Jour. Agr. Research, vol. 23, pp. 771–800, illus. 1923.
——— S. H. Eckerson, and R. W. Webb. The intracellular bodies associated with the rosette disease and a mosaiclike leaf mottling of wheat. *In* Jour. Agr. Research, vol. 26, pp. 605–608, illus. 1923.
——— R. W. Webb, and G. H. Dungan. Wheat rosette and its control. Ill. Agr. Exp. Sta. Bul. 264, pp. 273–296, illus. 1925.

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convenient to make observations in these counties for mosaic leaf mottling. In the spring of 1925 the writer observed mosaic on winter rye growing in infested soil at Granite City, Ill., and in similar soil which had been transported to Madison, Wis., for experimental purposes. What appears to be the same mosaic also was found by Dr. A. G. Johnson in winter rye growing as a cover crop in the orchards of the United States Department of Agriculture, at Arlington Experiment Farm, near Rosslyn, Va. Microscopic examinations of mosaic-infected rye plants from all these sources have shown the presence of cell inclusions which are very similar to, if not identical with, those associated with wheat mosaic, as previously described.[2]

This mosaic has not been observed on spring grains, but it does develop to a limited extent on spring-sown winter wheat when the season is cool.

This is the first mosaic disease known to occur on graminaceous plants in the central Corn Belt. The importance of the disease is difficult to estimate at this time. It manifests itself in several ways on wheat, depending upon the varieties. The greatest damage appears to be caused by the rosette condition which develops in certain winter varieties. Although many varieties do not develop the rosette condition, most of these exhibit the mosaic phase, and in some cases this apparently causes considerable injury. Although the mosaic symptoms of this disease appear to be identical with those of corn and sugarcane mosaic, further studies are necessary to determine whether these diseases are caused by the same virus.

DESCRIPTION OF WHEAT AND RYE MOSAIC

This disease seems to cause all of the symptoms associated with the mosaics reported on other Gramineæ. However, owing to the small size of wheat and rye leaves, the mosaic pattern is much smaller and less conspicuous than that on leaves of corn and sugarcane. Careful observations have shown that mosaic mottling occurs on a very few wheat plants in the late autumn, but the disease is not abundant until the new leaves develop in the early spring. The mottling consists of irregular streaks, which vary in length and width and tend to follow the direction of the long axis of the leaf (figs. 1 and 2). In some cases mottled leaves show a light-green pattern on the normal green background (fig. 1, *B* and *C*). Frequently, however, the greater proportion of the infected leaves are of the lighter green color, making it appear that there is a dark-green pattern on a light-green background (fig. 1, *D* and *E*; fig. 2, *B*). In certain varieties the leaves frequently develop light-yellow patterns or irregular strips, as shown in Figure 1, *F*. It is not uncommon to find mosaic mottling also on the leaf sheaths and glumes.

As in the case of the mosaic diseases of many other plants, the mosaic of wheat causes stunting or dwarfing and excessive proliferation in certain varieties. This condition, previously described as rosette, causes a field to take on a spotted or patchy appearance on account of the various sizes of the areas which contain the

[2] H. H. McKinney, S. H. Eckerson, and R. W. Webb. Op. cit.

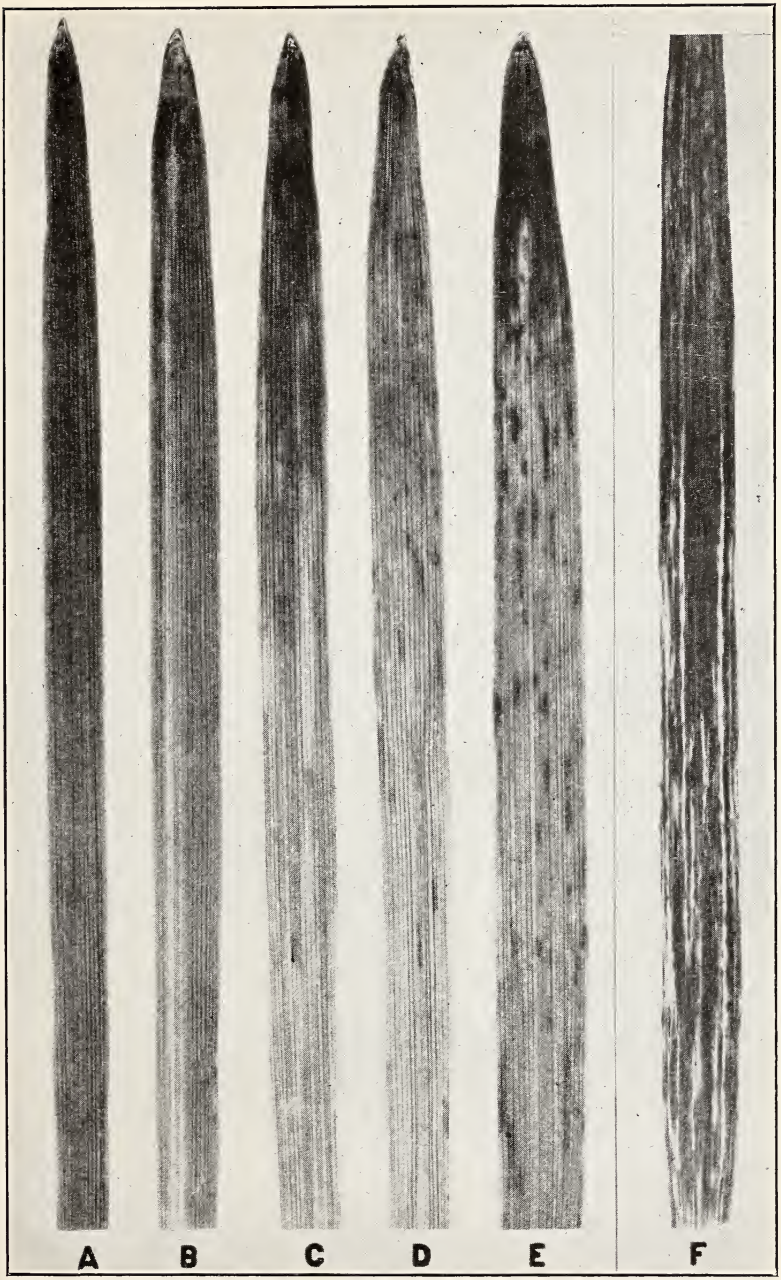

FIG. 1.—*A*, Portion of a healthy young Currell wheat leaf. *B*, *C*, *D*, *E*, Portions of young Currell wheat leaves showing mosaic (× 2). *F*, Portion of an older Currell wheat leaf showing severe mosaic. Natural size

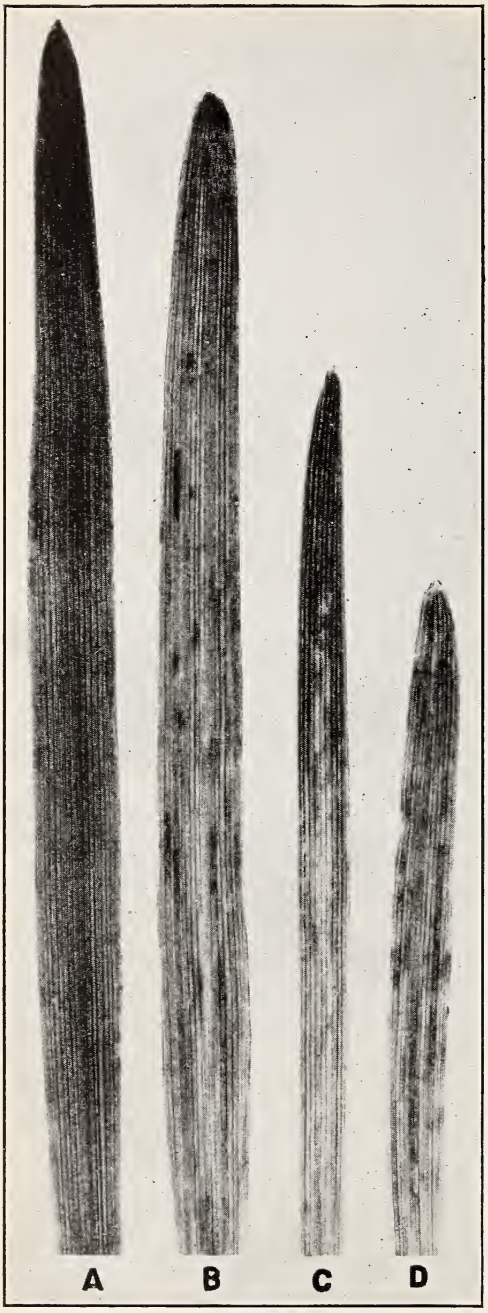

FIG. 2.—*A*, Portion of a healthy rye leaf. *B*, *C*, *D*, Portions of rye leaves showing mosaic (× 2)

stunted plants. This rosette condition is especially severe in Harvest Queen (also known as Red Cross and Salzer's Prizetaker) and several other varieties which are listed in other publications.[3]

The leaves of rosetted plants eventually become dark green in color, thus masking the mosaic mottling. However, cell inclusions have always been found when such plants were examined. Also when such plants send out new tillers mosaic has been found to occur on the new leaves of these tillers before the dark-green coloration develops.

Currell wheat seems unusually susceptible to severe leaf mottling, and observations covering several years indicate that mosaic frequently prevents the normal development of this variety. It is not uncommon to find infected Currell plants which are almost yellow in color, and in most cases such plants are rather stunted. This latter condition develops after the early spring period and is not confused with the rosette stage, which develops in some varieties early in the spring.

A LEAF MOTTLING NOT MOSAIC

Other types of mottling occur on wheat which may be confused in some cases with mosaic. Figure 3 shows a type of leaf mot-

[3] H. H. McKinney. Op. cit.
——— R. W. Webb, and G. H. Dungan. Op. cit.
R. W. Webb, C. E. Leighty, G. H. Dungan, and J. B. Kendrick. Varietal resistance in winter wheat to the rosette disease. *In* Jour. Agr. Research, vol. 26, pp. 261–270. 1923.

tling which appears to be due to faulty nutrition. This condition nearly always has a sequence of development on the leaves of a plant as follows: The flag leaves may show light-colored flecks on a predominatingly green background (fig. 3, *B*), but these flecks do not tend to follow the long axis of the leaf. Leaves next below the flag leaf may show a greater proportion of chlorotic surface, and the lower leaves may show very little green color (fig. 3, *D*). Although the pattern which develops on the leaves showing the advanced stages of this condition is similar to that which occurs in cases of severe mosaic, the coloration of the foliage differs in the two cases. In severe mosaic the chlorotic areas (fig. 1, *F*) usually are lemon yellow or faded yellow in color, whereas in the other case the chlorotic areas tend toward orange color. Cell inclusions have not been found in leaves showing the latter condition, but they are found usually without great difficulty in the cells of leaves showing the mosaic disease.

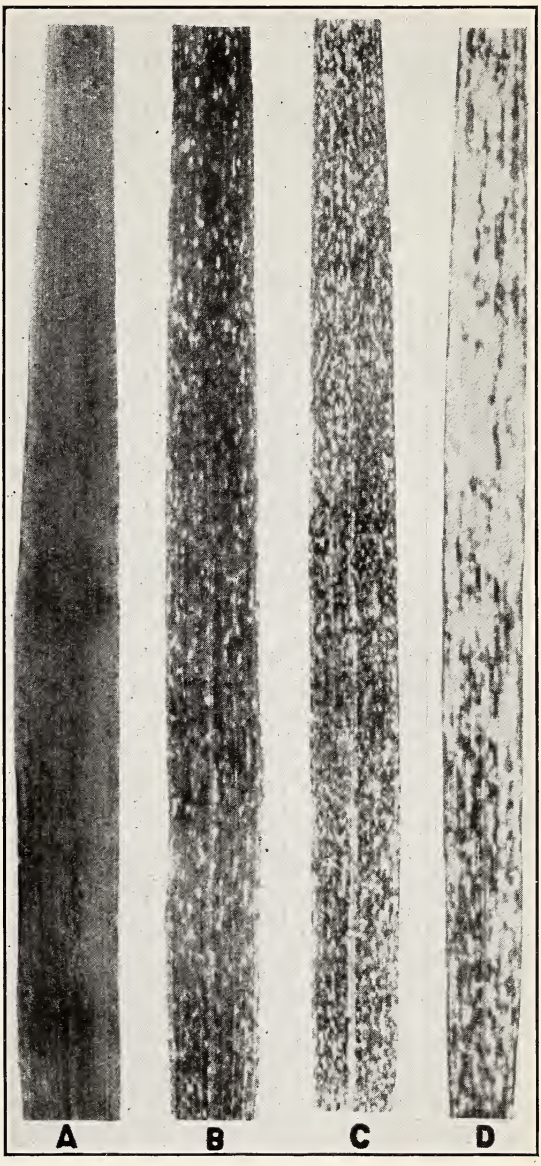

FIG. 3.—*A*, Portion of a healthy Harvest Queen wheat leaf. *B*, *C*, *D*, Portions of Harvest Queen wheat leaves showing a mottling not caused by the mosaic disease. This condition appears to be caused by faulty nutrition or some other soil conditions. Natural size

INOCULATION STUDIES

Six successful inoculation experiments have been conducted in disinfected soil in the greenhouse at Madison, Wis., with the Currell and Harvest Queen varieties of winter

FIG. 4.—Harvest Queen wheat plants from experiment No. 3: *A*, Healthy uninoculated; *B*, *C*, *D*, rosette following inoculation with juice and tissue from mosaic-infested Currell wheat plants. *A* has three tillers; *B*, *C*, and *D* have four, seven, and six tillers, respectively

wheat, and two similar experiments have been conducted with Wisconsin Pedigree No. 2 winter rye. The Harvest Queen wheat variety commonly develops both rosette and mosaic leaf mottling. It was important to determine, therefore, whether rosette would develop in Harvest Queen plants when inoculated with juice from a variety which develops only mosaic. The Currell variety therefore was used as a source of inoculum, because it develops mosaic without rosette.

The inoculum was prepared by grinding the leaves, sheaths, and crowns of infected plants with sterilized fine quartz sand in an ordinary porcelain mortar. All roots and old outer leaves and sheaths were carefully removed and discarded, and the plants were washed thoroughly in tap water to remove any soil particles which might adhere to the tissue. The ground pulp and expressed juice were introduced or applied into the seedlings near the bases of the coleoptiles by means of a sterile needle. A small quantity of absorbent cotton was then wrapped around the base of the plant, and this was saturated with inoculum. The uninoculated control seedlings were treated in a similar manner with the juice and ground tissue from healthy Currell wheat plants.

The seedlings used in the inoculation experiments were in the second or third leaf stage of development. Previous to inoculation, they were removed from the soil, and all soil was washed from the roots and bases of the tillers. After washing they were inoculated and returned to disinfected soil to continue their growth. The best results have thus far been obtained when the inoculated plants were grown at air and soil temperatures nearly comparable to those out of doors during the fall and early spring growing periods for winter wheat.

The results of these inoculation experiments are given in Table 1. It is of particular interest to note that all but one of the Harvest Queen plants affected with mosaic in the first five experiments became dwarfed. They also developed a deep-green color. The leaves were very stiff and brittle, and the plants proliferated excessively. In fact, these plants presented an appearance (fig. 4, *B*, *C*, *D*) which was very similar to, if not identical with, that of plants affected with wheat rosette under field conditions. It will be noted that several Harvest Queen plants developed mosaic in experiment No. 7. As the plants in this experiment were later severely attacked by powdery mildew, it was not possible to keep them for a time sufficiently long for rosette to develop. Although it is possible that mosaic and rosette are produced by separate causal agents and that the Currell variety is a carrier of the rosette causal factor, this seems doubtful. For the present it seems more reasonable to consider that both manifestations are due to a single cause.

Although the percentage of inoculated plants which developed mosaic is small, this is not surprising, as the mosaic diseases of other grasses and certain dicotyledons have not been transmitted readily by means of the expressed plant juice. Also, the winter-wheat plant does not develop normally under greenhouse conditions. Further studies must therefore be made to determine the influence of environmental factors on the host as well as on the disease.

TABLE 1.—*Results obtained with seedlings of Harvest Queen and Currell winter wheat and Wisconsin Pedigree No. 2 winter rye uninoculated and inoculated with juice and pulp from mosaic-infected Currell wheat*

Experiment	Variety	Total number of plants	Inoculated or control	Number of mosaic-infected plants				Number of healthy plants	
				Without rosette		With rosette			
				Total	With cell inclusions	Total	With cell inclusions	Total	With cell inclusions
No. 1	Harvest Queen	16	Inoculated	1	1	5	5	10	0
	do	16	Control	0	0	0	0	16	0
	Currell	32	Inoculated	13	13	0	0	19	0
No. 2	Harvest Queen	40	do	0		1	1	39	0
	do	30	Control	0		0		30	0
	Currell	39	Inoculated	1	1	0		38	0
	do	30	Control	0		0		30	0
No. 3	Harvest Queen	41	Inoculated	0		3	3	38	0
	do	13	Control	0		0		13	0
	Currell	48	Inoculated	1	1	0		47	0
	do	13	Control	0		0		13	0
No. 4	Harvest Queen	14	Inoculated	0		0		14	0
	do	24	Control	0		0		24	0
	Currell	29	Inoculated	2	2	0		27	0
	do	30	Control	0		0		30	0
No. 5	Harvest Queen	13	Inoculated	0		2	2	11	0
	do	12	Control	0		0		12	0
	Currell	12	Inoculated	0		0		12	0
	do	13	Control	0		0		13	0
No. 6	Harvest Queen	15	Inoculated	0		0		15	0
	do	16	Control	0		0		16	0
	Rye	25	Inoculated	1	1	0		24	0
	do	16	Control	0		0		16	0
No. 7[a]	Harvest Queen	13	Inoculated	5	5	[a] 0		8	0
	do	16	Control	0		0		16	0
	Currell	15	Inoculated	3	3	0		12	0
	do	14	Control	0		0		14	0
	Rye	21	Inoculated	3	3	0		18	0
	do	12	Control	0		0		12	0

[a] The wheat plants in experiment No. 7 were severely attacked by powdery mildew, and it was not possible to carry them for a sufficient length of time to obtain definite evidence on rosette.

The fact that one infected Harvest Queen wheat plant in experiment No. 1 did not develop the rosette condition may be explained on a genetic basis. Head-selection studies indicate that varieties which may be homozygous for the ordinary botanical and agronomic characters are not necessarily homozygous for susceptibility to mosaic. This makes it necessary to make special selection studies within a variety in order to obtain homozygous material for the critical study of the disease.

THE MOSAIC CAUSAL AGENT EXISTS IN CERTAIN SOILS

So far as known, this is the first mosaic the causal agent of which is definitely known to be associated with soils. Experiments have shown that the causal agent of this disease persists in fine river silt (gumbo) soils for at least six years. Susceptible varieties of wheat never have failed to develop the disease when grown in infested gumbo or sandy clay soils out of doors. Field observations seem to

indicate that the causal agent does not persist in sandy soils as long as it does in silt soil.

During the summer of 1920 two experiments reported previously [4] were conducted on infested soil at Granite City, Ill. In experiment No. 1 infested soil was placed in six galvanized-iron ash pails (5 gallons capacity). The soil in three of these pails was thoroughly disinfected with an 0.8 per cent solution of formaldehyde five weeks previous to sowing the seed. At the same time the remaining pails were thoroughly soaked with water. Harvest Queen wheat was sown in all of the pails in the autumn, and all pails were left in close proximity to each other throughout the fall, winter, and spring. In the spring 92 per cent of the plants in the pails containing the undisinfected infested soil developed rosette. Mosaic also occurred in these pails, but at that time the mosaic phase was not given great consideration, and complete counts were not made. All plants in the soil which had been disinfected were free from rosette and mosaic. Harvest Queen wheat growing simultaneously in the field in which this experiment was located developed 95 to 98 per cent of rosette. Mosaic also was prevalent, and various aerial forms of insects were abundant during the growing period.

Experiment No. 2 was conducted in two infested plats (A and B), which were 4 feet wide and 6 feet long and surrounded by a board frame. These plats were only a few inches apart. The soil in both plats was thoroughly disinfected with formaldehyde to a depth of 10 inches. Plat A was reinfested in the fall, when the seed was sown by scattering three-fourths of an inch of infested soil over the surface and in the seed trenches. Plat B was not reinfested. Harvest Queen wheat was sown in both plats. In the spring, mosaic and the rosette condition developed in 75 per cent of the plants in plat A. Wheat growing in plat B was healthy with the exception of a few diseased plants which developed at the edges of the plat. These plants undoubtedly became infected through the roots growing under the frame into the outside infested soil or through splashing or seepage of infested material into the edges of the plat.

During the summer of 1922 [5] a small plat (24 by 30 inches) of infested soil located in a large uniformly infested area at Granite City, Ill., was disinfected with formaldehyde. In the fall, Harvest Queen wheat was sown in the disinfected plat and also in much of the infested area outside of the plat. In the spring, mosaic and the rosette condition developed in 90 to 98 per cent of the plants growing outside of the disinfected plat, but all plants in the plat were free from mosaic and rosette, and they remained so throughout the growing season in spite of the fact that aphids and chinch bugs were abundant.

During 1922 infested soils from Granite City, Ill., and from Porter County, Ind.,[6] were transported to Madison, Wis., and placed out of doors in plats 3 by 4 feet in size.

The first plat contained infested Illinois soil, the second plat contained infested soil from Indiana, the third contained infested Illinois soil which was steam sterilized before sowing the seed, and

[4] H. H. McKinney. Op. cit.
[5] H. H. McKinney, S. H. Eckerson, and R. W. Webb. Op. cit.
[6] The Indiana soil was from an experiment field maintained on a farm near Wanatah, Ind., by the Purdue University Agricultural Experiment Station.

the fourth plat contained uninfested field soil obtained at Madison, Wis. In the autumn Harvest Queen wheat was sown in each plat. In the spring 95 per cent and 50 per cent of the plants in the infested Illinois and Indiana soils, respectively, developed rosette and mosaic. No mosaic or rosette developed in the steam-sterilized soil or in the Wisconsin soil.

This experiment was repeated in 1923 and 1924, and while the percentage of diseased plants has varied a little from year to year the general results have always been the same.

Each season since 1920 numerous experiments have been conducted with infested soil in small metal containers, and mosaic always has developed when susceptible varieties of wheat were sown and when the favorable environmental conditions were maintained. The disease has never developed in susceptible plants grown in uninfested soil in containers adjacent to those in which mosaic-infected plants were growing in infested soil.

Infested soil was transported to Alhambra, Ill., in 1920 and to Arlington Experiment Farm, Va., in 1923. In both cases mosaic and rosette developed in plants grown in the infested soil, and no mosaic occurred in the plants grown in uninfested soil.

While it would be possible to carry out elaborate experiments on the soil-transmission phase of this problem in insect-proof cages, it seems doubtful whether evidence so obtained would be more conclusive than that obtained by exposing all plants to the same degree of insect infestation, as was done in the experiments cited. In view of the evidence presented, it appears certain that the virus of wheat mosaic is carried in the soil. Whether it is held by the soil particles or by decayed plant tissue or whether it is contained in some soil-inhabiting and plant-infecting organism is not known.

As yet there is no evidence indicating that wheat mosaic is transmitted through the seed.

CONTROL MEASURES

As shown in previous publications,[7] the control of rosette is effected by the use of resistant varieties. This applies likewise to the mosaic leaf mottling, as both rosette and the mosaic are phases of the same disease. Infested fields should not be sown to Harvest Queen, Missouri Bluestem, Nigger, Penquite (Penquite's Velvet Chaff), Brunswick, or certain selections of Fultz, Indiana Swamp, and Illini Chief. These varieties and selections are all very susceptible to rosette as well as mosaic. Although the Currell variety does not develop rosette, it appears to be very susceptible to mosaic, and it should not be sown on infested soil. Most wheat varieties seem to be susceptible to mosaic, but in many cases the disease does not seem to be very severe. Selections have been made from Harvest Queen which apparently are immune from all phases of mosaic. These selections are being given further study. There is always the possibility of the resistant or apparently immune varieties serving as carriers.

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[7] H. H. McKinney. Op. cit.
——— R. W. Webb, and G. H. Dungan. Op. cit.
R. W. Webb, C. E. Leighty, G. H. Dungan, and J. B. Kendrick. Op. cit.

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