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Washington, D. C., November 15, 1920 by S. P. Doolittle

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S. P. DOOLITTLE

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THE INVESTIGATIONS of the cucumber mosaic reported in this paper were begun by the writer in 1914 at Hamilton, Mich., while a graduate student at the Michigan Agricultural College. In 1915 and 1916 they were continued at Big Rapids, Mich., and in 1917-18 at Madison, Wis., under cooperative relations between the Bureau of Plant Industry of the United States Department of Agriculture, the experiment stations of Michigan and Wisconsin, and certain interested pickle growers, under the joint direction of Dr. E. A. Bessey, Dr. L. R. Jones, and Mr. W. W. Gilbert. Laboratory facilities and material were furnished jointly by the cooperating parties and land, tools, and labor by a local pickle company.

The writer wishes especially to thank Messrs. Bessey, Jones, and Gilbert for assistance and supervision throughout the course of the work.

This paper was presented to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy.

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BULLETIN No. 879



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WM. A. TAYLOR, Chief

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November 15, 1920

THE MOSAIC DISEASE OF CUCURBITS.

By S. P. DOOLITTLE, *Assistant Pathologist, Office of Cotton, Truck, and Forage Crop Disease Investigations.*

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SCOPE OF THE INVESTIGATIONS.

DURING the last four years the more important diseases of the cucumber have been studied by various workers in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture. One of the most significant facts developed in the early work was the occurrence of a mosaic disease, heretofore practically unrecognized, which is probably at the present time the most widespread and destructive disease of cucumbers. The disease, however, is not confined to the cucumber but affects to a greater or less extent most of the cucurbits grown in this country.

The present bulletin deals with the nature, transmission, and overwintering of the disease in relation to cucurbits. The greater portion of the work has been done with the cucumber as grown for pickling purposes, in an attempt to develop field control measures.

THE MOSAIC DISEASE.

HISTORY.

Although mosaic has been reported in the field and greenhouse for some years, it is only recently that the disease has received detailed attention. Selby (26)¹ in Ohio in 1902 and Stone (29) in Massachusetts in 1909 recorded a mosaic disease on the leaves of greenhouse cucumbers, and Clinton (8) in 1908 noted a chlorosis of muskmelon leaves in Connecticut. It is not certain, however, that all

¹ The serial numbers in parentheses refer to "Literature cited" at the end of the bulletin.

these were true mosaic, as the disease was not proved to be infectious in any case and no mention was made of symptoms on the fruit. Selby (27) stated in 1910 that cucumber mosaic was transmitted like that on tobacco. There is no early record of the disease in the field, but it is certain that it had caused serious losses in the Central States for some time prior to 1914, and from evidence obtained from pickle men in the vicinity of Chicago it is practically certain that the mosaic had been a serious disease in that section for 10 to 15 years and was responsible for forcing at least one pickle company out of business. Ruggles and Stakman (25) in 1911 reported the mosaic as occurring in Minnesota and used the name wart disease in describing it. Coons (10) in 1915 reported that this disease was then causing serious losses in the field in Michigan and had been present in some localities for seven years. He described the chief symptoms and stated that the progress of the disease indicated that it was infectious.

The first proof of the infectious nature of the disease and the methods by which it is transmitted was presented in the papers of Gilbert (14), Jagger (17), and Doolittle (11) in 1916. Jagger (18) later reported the appearance of another type of cucumber mosaic, affecting only the leaves of the plant, and in a further paper (19) mentioned a third type as occurring on Summer Crookneck squash.

Stakman and Tolaas (28) mentioned nubbin or wart disease of cucumber as an infectious disease occurring in both the field and the greenhouse in Minnesota. McClintock (22) in 1916 observed possible cases of transmission of the disease through the seed and described its occurrence in the district near Norfolk, Va. Clinton (9) also gave data as to the severity of the disease in Connecticut.

Freiberg (13) in 1917 reported the disease on various cucurbits in Missouri and described inoculation experiments. Jagger (20) in 1918 also reported numerous cross-inoculations from cucumber to other cucurbits and showed that cucumber mosaic could be transmitted to plants outside the Cucurbitaceæ.

These papers include all the available material on cucumber mosaic to the present, with the exception of an abstract by Doolittle and Gilbert (12) which dealt with certain phases of the work here considered in greater detail.

GEOGRAPHICAL DISTRIBUTION.

The general occurrence of cucurbit mosaic in the field was not recognized until after these studies were begun, but investigation has shown that it is widely distributed on Cucurbitaceæ throughout the United States. Doubtless the extensive cultivation of cucumbers makes it seem more common on that crop, but it may occur on practically all cucurbits in localities where it is found on cucumbers.

The disease is probably most widespread and serious in Wisconsin, Michigan, Indiana, northern Illinois, and on Long Island. It is re-

ported to have caused serious losses in Illinois as early as 1908 and was present about as early in Michigan and Wisconsin. The center of the pickle-growing industry is located in these States, which devote a large acreage to the crop. Here the disease is present to some extent in almost all localities, and in most cases there is infection every year.

The disease occurs commonly in New York and is becoming serious in the seed-growing districts of Ohio and Iowa. It has been found quite prevalent in the fields around Rocky Ford and Greeley, Colo., causes severe losses in the trucking region about Norfolk, Va., and does much injury in many sections of Florida and Louisiana. Recent inspections of the principal city markets of the Western and Pacific Coast States have shown the mosaic disease to be present in practically all of them, and in many cases it was very prevalent. It is also reported in the field from Maine, Massachusetts, Minnesota, Vermont, Connecticut, West Virginia, New Jersey, Pennsylvania, Georgia, Texas, California, Nebraska, and Ontario, Canada.

In the greenhouse it has caused serious injury for several years in Michigan, Wisconsin, Illinois, and New York and has also been reported from Mississippi, Ohio, Indiana, Minnesota, Pennsylvania, Louisiana, and Kansas. Up to the present the disease has been found only in the United States and Canada, but the fact that it has not been reported from other parts of the world may be due to its not having been extensively studied elsewhere.

ECONOMIC IMPORTANCE.

Cucurbit mosaic is the most serious disease of cucumbers in the Middle West, and yearly it increases in severity in districts where this crop is grown on a large scale. The disease is not confined to the cucumber, but causes considerable loss on the muskmelon and to a less extent on squash and pumpkin.

The greater losses on the cucumber are due partly to the special severity of the disease on the fruits of this host, but more especially to the fact that the acreage of cucumbers far exceeds that of any other cucurbit. The increase in the pickling and trucking industries in certain sections has localized much of this crop in restricted areas, and thus furnished conditions very favorable to the spread of such a highly infectious disease. The other cultivated cucurbits ordinarily are grown on a smaller scale, and thus the loss is distributed among many small growers, so that it is less noticeable. Cucumber plants infected with mosaic are practically worthless, owing to the great reduction in yield and to the fact that the fruits produced are so mottled and deformed that they are usually refused by pickling companies and are of little value for market purposes. The disease spreads very rapidly, and many fields may become 50 to 75 per cent diseased almost before picking has begun. As a result of

the losses from mosaic, many growers, especially those in certain sections of the Middle West, have ceased to grow cucumbers, despite increased prices (Pl. I, C).

In the case of forcing cucumbers, growers occasionally lose an entire crop, because, in addition to the reduced yield and deformed fruit, mosaic often causes the sudden wilting and death of the plants under glass. An additional factor in the loss occasioned by mosaic is the fact that affected table stock sells for about one-fourth the price obtained for sound fruits, owing entirely to the effect on their appearance.

Of the other cultivated cucurbits squash and muskmelon seem most susceptible to the mosaic, but neither of these plants is injured as severely as the cucumber. The muskmelon vines are stunted and bear only a few fruits, which are inferior in quality but only occasionally show mosaic symptoms. Squashes are similarly affected and in addition sometimes have warty and deformed fruits, the Summer Crookneck variety being most often and most severely attacked. The disease is less common and of minor importance on the pumpkins, gourds, and ornamental cucurbits, which are of less commercial value.

CUCURBIT HOSTS.

Most of the species of the family Cucurbitaceæ appear to be susceptible to mosaic. Field observations have proved that most cultivated species are commonly affected, and that the disease also occurs on wild species. The host range has been further extended by cross-inoculation experiments which included most genera and species of cucurbits found in this country and many varieties of the commoner cultivated species.

Most of the field inoculation tests were made during 1916 and 1917. All inoculated plants were kept under insect-proof cages, and reciprocal inoculations were made in most cases. The various species were usually inoculated in stems or leaves with the expressed juices of mosaic cucumber plants, but many successful inoculations were made between other species, leaving no doubt that the disease is identical on the various cucurbit hosts. From 10 to 50 successful inoculations have been made with all the species noted below.

In the case of cucumber, *Cucumis sativus* L., 15 varieties were inoculated successfully, and all seemed equally susceptible. Mosaic was also produced on the West Indian gherkin, *C. anguria* L., on a closely related variety, *C. grossulariaeformis* Hort., and on *C. metuliferus* Mey.

Inoculations on 11 varieties of muskmelon, *Cucumis melo* L., have all produced the disease, including the pomegranate melon, *C. melo* var. *dudaim* Naudin. Seven varieties of squash and four varieties of pumpkin, *Cucurbita pepo* L., *C. moschata* Duchesne, and *C. maxima* Duchesne, have also been infected.

On the gourds infection occurred on 12 varieties, including *Cucurbita pepo* L., *Luffa cylindrica* Roehm., *L. acutangula* Roxbg., *Lagenaria vulgaris* Ser., and *L. leucantha* Rusby.

Mosaic has also been produced by inoculation on the following species: *Momordica involucrata* E. Meyer, *M. charantia* L., *Ecballium elaterium* A. Rich., *Benincasa hispida* Cog., and *Trichosanthes anguina* L.

The wild species, *Micrampelis lobata* (Michx.) Greene, is common in many parts of the country both as an ornamental vine and growing wild and is often diseased. The identity of this disease with that on the cucumber as well as with that which occurs on the less common wild species, *Sicyos angulatus* L., has been proved by repeated inoculation.

From data so far collected, the watermelon, citron, and other species of *Citrullus* seem partially resistant to the disease. No successful inoculations have been made by the writer on any plants of this genus with the exception of the green-seeded citron, *Citrullus vulgaris* Schrad., and watermelons grown in the field have never been found infected although often intertwined with mosaic-diseased cucurbits. Jagger (19) reported having obtained a single case of mosaic on watermelon by inoculation, but was not able to repeat such infection. He also noted the disease on the green-seeded citron, but not on the red-seeded variety. Freiberg (13), at the Missouri Botanical Gardens, also reported mosaic on the citron and showed photographs of the disease.

CROSS-INOCULATIONS TO OTHER PLANTS.

INOCULATIONS FROM MOSAIC CUCUMBERS TO PLANTS OF OTHER FAMILIES.

Certain field observations have at times suggested that cucurbit mosaic might possibly be transmitted to plants of other families. An example of such a case occurred at Madison, Wis., in 1916. A few plants of *Martynia louisiana* Mill. appeared in one of the cucumber plots, the seed having been accidentally included with that of the cucumber. A large number of the cucumber plants became infected with mosaic early in the season, and a few of the martynia plants also developed a disease of the mosaic type later in the summer, the circumstances suggesting a possible transference of the infection from the cucumber. Inoculations were made from the mosaic martynia to healthy cucumber plants and also from mosaic cucumber to healthy martynia, but all the inoculations gave negative results.

Most of the inoculations from cucumber to plants outside the Cucurbitaceæ, however, have been with plants known to be subject to infectious mosaic diseases, such as tomato, tobacco, bean, petunia, and pokeweed (*Phytolacca decandra* L.), although a few inoculations have been made on plants subject to unknown chlorotic diseases.

The methods used in this inoculation work were very similar to those used in the other cucumber-mosaic studies. Where field inoculations were made, the plants were protected with insect-proof cages wherever possible, and in the greenhouse all plants used in such inoculations were kept isolated from other mosaic experiments. The inoculum was prepared in much the same way as in other cucumber-mosaic inoculations, either the expressed juice or crushed tissues of mosaic plants being used. Where the juice of a mosaic plant was employed, the parts of the plant used as inoculum were passed through a sterilized food chopper and the juice expressed and filtered through filter paper. Inoculations were made at from three to five points in each of the younger leaves, a drop of the expressed juice being pricked into the leaf with a sterile needle. The stem usually was inoculated at one or more points, a slight incision being made with a sterile scalpel carrying a drop of the inoculum.

TABLE I.—Record of inoculations from mosaic-diseased cucumber plants to plants of other families.

Date inoculated.	Plant inoculated.	Preparation of inoculum.	Number of plants inoculated.	Results.	
				Number of mosaic plants.	Date last observed.
Aug. 4, 1916	Tobacco.....	Expressed juices.....	3	0	Aug. 17, 1916
Mar. 11, 1917	do.....	do.....	4	0	Mar. 26, 1917
Apr. 27, 1917	do.....	do.....	4	0	May 28, 1917
May 8, 1917	do.....	do.....	8	0	Do.
May 30, 1917	do.....	Crushed leaf tissues.....	20	0	June 14, 1917
Oct. 1, 1917	do.....	do.....	18	0	Oct. 30, 1917
Nov. 5, 1917	do.....	Expressed juices.....	21	0	Dec. 1, 1917
Aug. 4, 1916	Tomato.....	do.....	3	0	Aug. 17, 1916
Aug. 18, 1916	do.....	do.....	6	0	Aug. 31, 1916
Feb. 23, 1917	do.....	do.....	4	0	Mar. 20, 1917
Feb. 30, 1917	do.....	do.....	6	0	May 2, 1917
Apr. 5, 1917	do.....	Crushed leaf tissues.....	15	0	May 8, 1917
Oct. 8, 1917	do.....	do.....	12	0	Nov. 19, 1917
Dec. 8, 1917	do.....	Expressed juices.....	15	0	Jan. 12, 1918
Aug. 4, 1916	Wax bean.....	do.....	9	0	Aug. 17, 1916
Do.....	Lima bean.....	do.....	6	0	Do.
Feb. 15, 1917	Red kidney bean.....	do.....	15	0	Mar. 10, 1917
Mar. 24, 1917	do.....	do.....	10	0	Apr. 12, 1917
Sept. 7, 1916	<i>Martynia louisiana</i>	do.....	12	0	Sept. 23, 1916
Aug. 15, 1916	Potato.....	do.....	8	0	Do.
Aug. 16, 1916	Pokeweed (<i>Phytolacca decandra</i>).....	do.....	5	0	Sept. 30, 1916
Mar. 22, 1916	Petunia.....	do.....	6	0	Apr. 10, 1916
Aug. 1, 1917	<i>Ambrosia trifida</i>	do.....	12	0	Sept. 1, 1917
Aug. 5, 1917	do.....	do.....	10	0	Do.

Where the crushed tissues of the mosaic plant were used, a fragment of one of the young leaves was crushed in a sterile dish with sterile instruments and small portions of this crushed material inserted in slight incisions made at one or two points in the stem of the plant inoculated and other pieces sometimes pricked into the young leaves.

The results of all the inoculations from mosaic cucumber to plants outside the cucurbits have been negative,¹ as shown by Table I.

¹ Recent experiments (1910) indicate that cucumber mosaic may be transmitted to *Martynia louisiana* by means of aphids taken from mosaic cucumber plants. Inoculations from martynia plants infected in this manner have also produced the disease on the cucumber.