

A STUDY OF SOME VIRUS DISEASES OF CELERY

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L. C. Cochran^{1/}

INTRODUCTION

Since the demonstration of the communicable nature of plant viruses, this field of plant pathology has expanded with such rapidity that it has now assumed front-rank importance. Scarcely an issue appears of the journals dealing with plant diseases that does not devote considerable space to plant viruses. Smith and Brooks (28, p. 11) report the number of economic crop plants on which a virus disease has not yet been reported to have dwindled to three: asparagus, oats, and flax. Although most of the work on virus diseases has been in the nature of host range, symptomatology, transmission, etc., rapid progress is being

^{1/} The author is indebted to Dr. Ray Nelson for suggestions and criticism throughout the course of this investigation and for help with the photograph work. Acknowledgment is also made to Dr. E. A. Bessey for a critical reading of the manuscript, to Professor F. C. Strong for assistance with photography, and to the guidance committee for suggestions and encouragement.

made in investigations to determine the nature of the virus itself. Stanley (29, 30) has stimulated renewed interest in this phase of virus research by his reports on the isolation of a protein from mosaiced tobacco plants which, when used as inoculum, produces typical tobacco mosaic. This report, while hailed by those who believe the virus to be a chemical entity, has given a new impetus for research to those who prefer to accept a biological explanation of the nature of the causal agent. The economic aspects of increasing losses from virus diseases of plants and the large number of students engaged in research on their various phases will undoubtedly go far to advance our knowledge of this branch of science in the near future.

A virus disease was first reported on celery by Poole (20) in 1922 from New Jersey. In 1924 Foster and Weber (6) described a disease on celery in Sanford, Florida, which was symptomatically distinct from the New Jersey form. This disease has since been studied by Doolittle and Wellman (3) and also by Wellman (34, 35, 36, 37, 38, 39, 40) and identified as Celery virus I. Elmer (4) reported infection on celery with a mosaic naturally occurring in Iowa, and Harvey (9) reported what appeared to be a mosaic on celery in Minnesota. Wellman (36) and Johnson and Grant (13) produced infection on celery with cucumber mosaic^c and tobacco ring-spot viruses. Severin (26) transmitted with aphids

two viruses which affect celery in California. Severin (24, 25) in 1929, reported infection of celery with aster yellows. Kunkel (16), after repeated negative results with his strain of the aster yellows virus, obtained infection with viriferous hoppers sent to him by Severin. Gardner, Tompkins, and Whipple (7) reported mechanical transmission of the tomato spotted ^{it} with virus to celery.

It is well established then that celery, like tobacco, cucumber, etc., is subject to infection by several viruses. Some of these seem to occur naturally on celery and others have been transferred only by inoculation. Infection of celery by a known virus merely adds another host to its established range; but this is important, for it may define symptoms which will assist in the identification of a supposedly naturally occurring disease in another region. Confusion has resulted from the assumption of the identity of a certain virus in one section of the country with another in a different section. In this study an attempt has been made to define the characteristics of the disease and to determine the properties of the virus which could be used to classify the virus diseases which occur in nature on celery.

Of the virus diseases which occur naturally on celery, accessibility has limited this study to four. For the sake of clarity, names will be assigned to the diseases caused by the viruses as follows: southern celery mosaic, as designated by Wellman; Celery virus I; west coast celery

mosaic, as designated by Severin, Western celery mosaic; leaf malformation type, as described by Poole, Celery fern leaf; and the local celery mosaic as Michigan celery mottle.

EXPERIMENTAL WORK

Sources of Materials

The sources of the viruses used in this study are listed in table 1. All of them were obtained from living plants which were secured from workers who kindly supplied material for this study. After the viruses were inoculated to healthy greenhouse-grown celery plants and the subsequent development of disease was observed, they were transferred to broad-leaf tobacco and these plants caged as a source of material for further study.

Symptoms on Celery

Celery, like many other plants, varies markedly in symptom expression when infected with different viruses. Environmental factors, such as temperature, moisture, soil fertility, etc. are very important. Smith and Brooks (28), in discussing such factors, have enumerated many instances where the entire symptom picture has been modified by a change of one or more of the environmental factors. Johnson and Hoggan (15) have shown that, except on differential hosts, symptoms are of little value as a diagnostic factor. Nevertheless, environmental conditions in a field are similar enough so that plants showing different symptoms may be selected with some assurance that they are infected with different viruses or strains of the same virus. This fact

TABLE 1

Viruses Used in Comparative Studies on Celery

Virus	From whom obtained	Host source	Place of collection	Date
Michigan celery mottle	Author	Celery	Kalamazoo, Mich.	Aug., 1932
" "	"	"	Comstock, Mich.	" 1932
" "	"	"	East Lansing, Mich.	Oct., 1932
Celery fern leaf	"	"	Kalamazoo, Mich.	Aug., 1932
" "	"	"	East Lansing, Mich.	Oct., 1932
Celery virus I.	H. H. Wedgeworth	<u>Commelina communis</u>	Everglades, Fla.	Nov., 1933
Western celery mosaic	M. W. Gardner	Celery	Delta, Calif.	Oct., 1933
" "	J. B. Kendrick	"	Davis, Calif.	Nov., 1933
" "	Ray Nelson	"	Venice, Calif.	March, 1934
Spotted wilt	M. W. Gardner	Calla lily	Berkeley, Calif.	Feb., 1935
Tobacco virus I.	J. Johnson	Tobacco	Madison, Wisc.	April, 1935
" "	W. D. Valleau	"	Lexington, Ky.	July, 1935
Tobacco ring-spot	" "	"	" "	" , 1935
Cucumber virus I.	J. Johnson	"	Madison, Wisc.	April, 1935
" "	S. P. Doolittle	Tobacco and cucumber	Beltsville, Md.	Nov., 1935

may be further substantiated by certain diagnostic tests which will be discussed later. In view of this, it is very important to have a complete description of the symptoms of the various virus diseases affecting celery in the field.

Southern Celery Mosaic.—The disease caused by Celery virus I was first reported by Foster and Weber (6) in Florida in 1924. Its increase in severity attracted the attention of Doolittle in 1929, who made a study of the disease (2,3). This work was continued by Wellman, who made a very excellent study of the trouble (34, 35, 36, 37, 38, 39, 40) and identified and named the causal virus. A similar trouble on celery in California has been reported by Severin and Freitag (27) but, as will be shown later in this paper, it is entirely different.

Wellman has described infection on some 91 host species in 23 widely separated families. A number of these are perennial weeds in Florida and are important as primary sources of inoculum. Infection on certain monocotyledonous hosts, such as corn, banana, and Commelina sp. seems important in differentiating the virus.

Although symptoms on celery have been fully described by Doolittle and Wellman (3), a brief description will be given here for comparative purposes. On celery the virus produces a splotchy mottling of the leaf blades which varies from a vein-clearing to a blotchy, discrete, yellowish-green pattern. On the petiole, initial symptoms usually start with yellow or buff streaks on and below the rachises. These may turn dark and extend entirely down the petiole,

eventually causing the death of the leaf. Others may clear somewhat and become a dull yellow. Symptoms are most marked on large plants, the plants being much stunted and yellowed. The stunting seems to be due primarily to a weakening, with a consequent prostration of the petioles rather than to a noticeable shortening of the petiole.

Young seedlings artificially infected develop faint vein-clearings after 10 days followed by a sharp oblique curving of the petioles toward the ground. The vein-clearing soon changes to a sharply contrasting mottle. Plants infected through viriferous aphids develop initial symptoms a little sooner than those artificially inoculated. Lesions on the petioles appear after about 15 days. They develop, as described above, on older plants, near the rachises, seemingly running in from the leaflets. Some develop rapidly, forming black streaks down the petioles. These usually result in the death of the plant. Others form buff-colored areas and seemingly recover. After 20 to 30 days the plants that have withstood the effects of the disease lose some of their color contrast and become irregularly mottled. No malformations or filiformities were noted.

Michigan Celery Mottle.—For several years an apparent mosaic has been noted on celery in widely separated parts of the state. Surveys have been made to determine the correlation of weed hosts with the occurrence of the disease but the random distribution of the trouble gave no indication as to the source of the infectious material. Mechanical inoculations were made on celery by leaf mutilation

and hypodermic-needle punctures without success. In 1933, juice was rubbed onto 6 broad-leaf tobacco plants. After 10 days, 3 of these plants developed a general chlorosis. Repeated attempts with the same method to inoculate celery resulted in only an occasional infection. In 1934, the author used Rawlins' (23) technique and was able to transmit the virus to a majority of the plants inoculated.

Celery seedlings inoculated with freshly expressed juice from typically mottled celery plants developed decidedly cupped heart leaves after 12 days. The petioles are seemingly unaffected but the leaflets become strongly convexed. After 20 days the heart leaves seem to recover somewhat. On close examination, rather indistinct color patterns can be seen. As these leaves become older, these patterns become yellow blotches. Fully expanded leaves resemble a green, oily surface on which a yellow aqueous solution has been spattered (figs. 1 and 2). The splotching is incongruent with the leaf veins and occasionally forms small islands either in the green or in the yellow. Mosaicked plants show none, or very little, stunting. Occasionally, naturally infected plants become rosetted through the formation of a large number of leafstalks. In the latter case, a few filiformities, such as described by Poole (20), have been observed, and this has been assumed to be due to infection with 2 viruses.



Fig. 1. Mature celery plant affected with Michigan celery mottle. Taken from a field near Kalamazoo, Michigan.



Fig. 2. Slightly enlarged view of a celery leaflet affected with Michigan celery mottle showing splotched and ringed patterns.

Celery Fern Leaf.—The mosaic disease described by Poole (20) is not uncommon throughout the celery-growing districts of Michigan. Some fields have shown as high as 25 per cent infection, and in certain localized spots in these fields, infection has approached 100 per cent. Surveys of these fields have revealed several apparently badly mosaicked weeds, but inoculations on celery failed to produce typical symptoms.

The disease is widely spread but is responsible for only a small amount of damage.. Elmer (4) described a virus disease which was characterized by the occurrence of filiformities and of mottling on celery in Iowa. It is quite possible that he was concerned with 2 viruses on the same plant, a condition commonly observed in Michigan fields. Wellman (36) reported occasional plants showing fern-leaf symptoms in Florida. Harvey (9) reported celery mosaic mostly of the mottling type in Minnesota but his illustrations depict plants showing fern-leaf symptoms also. Wellman (36) and Johnson and Grant (13) produced typical fern-leaf symptoms on celery with Cucumber virus I.

Young plants inoculated by the Rawlins' technique or by the aid of aphids^e develop a convexing and vein-clearing in the young leaves. At this stage the symptoms are almost identical with those produced by the Michigan celery mottle virus. A few days later the plants seem to partially recover and the leaflets assume a nearly normal position. After 20 days the heart leaflets show some savoying; the

edges of leaflets are turned under as though they had become stuck when the leaf was expanding. Other leaflets may appear as if the lamina had been pinched edgewise between the thumb and finger. Successive leaves become savoyed and truly fern-leaved (fig. 3). Usually the plants produce salable stalks but occasionally plants may be dwarfed and rosetted. These also exhibit extrorse malformations, shoe-strings, and hair leaves. From observation, it is believed that this latter condition results only from seedling infection. Symptoms of this type were observed commonly in one field in which all the plants had been grown in one greenhouse. Seedbed infection would also help to explain the random distribution of field infection. The expression of symptoms is subject to modification by changes in temperature. Infected plants placed in a warm room develop almost normal leaves but when returned to a room with temperatures from 15° to 20° C., they develop typical symptoms.

Western Celery Mosaic.—The western celery mosaic reported by Severin and Freitag (26) has been increasing in severity since 1930. It was first reported to the author as serious by M. W. Gardner in 1931. Ray Nelson observed the disease as epidemic in the celery district around Venice, California, in 1934. At the present time the virus has invaded regions as far north as the Sacramento Valley. It has not been reported from other states.



Fig. 3. Leaf from a mature celery plant affected with fern leaf; natural infection. Typical pinching without mottling is shown.

Symptoms on celery are very characteristic (fig. 4). The first evidence of infection is a clearing of the tissue adjacent to the veins and veinlets in the heart leaves. As the disease progresses, the green islands between the veinlets decrease in size, thus giving a yellowish appearance to the whole leaf. Some leaves become entirely yellowed; others lose only the green color adjacent to the larger veins and become contrastingly mottled. After this secondary chlorosis develops, the heart leaves become strongly convexed. The petioles and rachises remain upright. The curled appearance is entirely due to a cupping of the individual leaflets. The chlorosis continues down the petioles, forming a true mosaic-like mottle. The pattern is composed of elongated splotches of yellow (which are parallel with the ribs of the petiole) on a green background.

When the Western celery mosaic virus becomes systemic it always produces a stunting. Some plants may be found with very marked symptoms and yet show very little stunting. If such plants are compared 2 weeks later with healthy plants it can be easily seen that they have grown very little since the symptoms first appeared. The apical growth fails to develop on occasional plants which become infected when they are quite small, and the development which occurs from adventitious buds results in a multiaxial plant.

Green varieties develop less chlorosis and hence are more able to endure the disease. Some show very little of the vein-banding pattern but the individual leaflets are



Fig. 4. A and B, heart leaves from partially mature celery plants affected with Western celery mosaic.
C, leaf of normal plant.

usually more markedly convexed than in the yellow varieties. Curly leaf, a semigreen variety, seems to suffer less ill effects from the disease than any other variety.

Plants which have endured the infection for a long time seem to lose some of the distinctness in the netted pattern and the larger veins become more pronounced (fig. 5). Sometimes the bases of the individual leaflets which have been formed since infection occurred become twisted so that the ends of the leaflets are vertical to the plane of the leaf (fig. 5).

Young inoculated celery plants develop, at 21^o C., a very fine netted pattern 6 to 10 days after inoculation. The pattern progressively becomes more pronounced and develops as described on older plants. Infection is never followed by death unless accompanied by other complications.

The symptoms of the Western celery mosaic on celery differ, then, essentially from the Florida form in that the affected part of the plant regularly develops a netted pattern. This is especially typical of the initial symptoms which always appear on the heart leaves. Splotching occurs only on the old leaves. The petioles are mottled without necrosis.



Fig. 5. Leaves of partially mature celery plant affected with Western celery mosaic. A, youngest heart leaf; B and C, progressively older leaves from the same plant.

Transmission

The virus have been transmitted both by the aid of aphids^e and by artificial juice inoculation. In inter-transmission studies between different host species, the viruses, when recovered, always produced their respective characteristic symptoms when inoculated onto celery. Some hosts were more difficult to infect than others. Passage through tobacco (Nicotiana tabacum) seems to enhance the virulence of the virus, possibly merely by an increase in concentration.

Aphids^e.—Various workers have transmitted viruses found on celery and other plants to celery with aphids^e. Poole (20) transmitted his filiform mosaic to healthy plants with the peach aphid (Myzus persicae). Doolittle and Wellman (3) transmitted Celery virus I with the cotton aphid (Aphis gossypii Glov.) and they (3), as well as Elmer (4), transmitted cucumber mosaic to celery with the same aphid. Severin and Freitag (26) transmitted Western celery mosaic and their celery calico with 10 species of aphids^e (not specified). He found the cotton aphid was able to transmit both of these viruses after feeding only 5 minutes on diseased plants and 5 minutes on healthy plants. These aphids^e were merely mechanical carriers, as they failed to transmit the virus after the first day.

The Western celery mosaic virus was transmitted with aphids by the author. Celery plants infected with the virus and sent to the writer by J. B. Kendrick from Davis, California, were also infested with a black aphid, Anuraphis apiifolia Theobald.²

² Identified by Dr. Edith Patch.

— This aphid was transferred to celery and allowed to colonize. After 15 days, typical Western celery mosaic developed only on plants on which the insects had been placed. Single aphids^e taken from the diseased plants transmitted the virus to healthy plants after 10 hours' feeding. The black aphids^e preferably always fed on the youngest heart leaves and as far down in the heart as they could wedge themselves. This fact was at first thought to have some correlation with the development of the initial symptoms in the heart leaves, but transfer^{of the virus} was also accomplished with the cotton aphid which feed mostly on the undersides of the old leaves.

Western celery mosaic was easily transmitted by the cotton aphid. Healthy celery plants on which a single aphid had been allowed to feed for 12 hours, after having fed on infected celery plants, developed typical symptoms after the usual incubation period. Unlike the black aphids^e described above, the cotton aphids fed mostly on the lower surfaces of the old leaves. Occasionally, on slow-growing plants, they colonized on the tender heart leaves.

The Western celery mosaic was transmitted to several other hosts by the aid of aphids^e. These will be discussed later.

Both viruses found on celery in Michigan, as well as Celery virus I and the Western celery mosaic virus, were readily transmitted from celery to celery with the cotton aphid. None of the black aphids were freed of the western

virus and thus were not tried for transmission of the other viruses. In accordance with other work, a culture might have been obtained by removing the newly borne young to healthy plants before they had a chance to feed. It seems quite logical that this aphid should be as able to transfer the other viruses as well as the western virus.

Other Insects.—The rapidity with which western celery mosaic spreads in the field and the occurrence of groups of celery plants affected with other mosaic diseases are good indicators of insect transmission. When, after close microscopic examination, no aphids were found, attention was turned to other insects. Many references in ^{the} literature have placed certain groups of insects under suspicion. The following were tested for transmission of the 4 celery viruses without success: tobacco thrips, mealy bugs, bean leaf hopper, tarnished plant bugs, white flies, several unidentified leaf hoppers, and red spiders.

It is possible that a few aphides which escape detection may account for local infections in the field. Tests in the college experimental field revealed an extensive and systematic spread of the Western celery mosaic which, in every case, was complete by the end of the season. This pointed strongly to a spread by insects other than aphides. Bean leaf hoppers and tarnished plant bugs were the most numerous during the chief period of dissemination in August and September. In repeated caging experiments with several hundreds of each of these insects, respectively, the virus

was not transmitted in a single case. The feeding of a single ~~the~~hished plant bug over a period of 24 hours is fatal to about 50 per cent of young celery seedlings, while 10 bean leaf hoppers produced no apparent injury after a feeding period of 5 days.

Grafting.—Several modified inarch grafts between mosaicked and healthy celery plants failed to transfer the disease. Similar grafts between mosaicked Commelinas and celery plants failed to transfer the virus. Owing to the structure of these plants, actual tissue union may not have been accomplished.

Mechanical Transmission.—Mechanical transmission to celery and to other hosts has been accomplished with all of the viruses found on celery. Little success was attained with the ordinary rubbing methods without the use of carborundum, as reported by Rawlins and Tompkins (23). Celery, unlike the more easily infected solanaceous plants, is almost entirely devoid of epidermal hairs. This fact makes it necessary to break the epidermal cells, and for this purpose carborundum is very effective.

Since the method of Rawlins and Tompkins has not yet been widely used, and since it has been of such importance in this work, the essential details will be briefly outlined. The effective agent of the method is powdered carborundum, size 370 grains, which, according to the originators of the method, when rubbed on the leaves penetrates some of the epidermal cell walls, yet does not cause

sufficient injury to kill the cells. This carborundum is dusted on the leaf to be inoculated with a dry camel's hair brush. The leaf is then rubbed lightly with a swab made by wrapping a pinch of absorbent cotton, which has been dipped in freshly expressed viruliferous sap, around the tip of a pair of tweezers. The virus apparently enters the plant through the injured epidermal cells. The swab should be used very lightly, or too much injury will result. The excess viruliferous sap should be removed by a stream of water. Plants not irrigated directly after being rubbed wilt more than irrigated ones. The wilting is probably due to a squeezing-out of water from the cells into the inter-cellular spaces by the pressure exerted on the leaves in the rubbing process. Plants usually recover entirely from a moderate amount of wilting. In most cases some cells will be killed but a sufficient number will be injured only enough to provide an avenue for entrance of the virus. This method was found to increase the take on all hosts tried, and thus was used throughout this study when mechanical transmission was involved.

Seed Transmission.—The important problem of seed transmission is one which can be decided~~ly~~ only by growing large numbers of seedlings from seed harvested from typically diseased plants. Plants naturally affected with Michigan celery mottle and Celery fern leaf in 1932 matured seed in 1933. Seedlings grown from this seed were set in the field in 1934. Plants infected with the Western celery mosaic

TABLE 2

Results of Studies on Seed Transmission of the Viruses Affecting Celery, with Seed
Harvested from Mosaic Plants

Virus	Host parent	Year grown	Number of seedlings grown	Number of seedlings diseased	Symptoms
Celery fern leaf	Michigan Golden	{ 1934	38	0	—
	Golden Phenomenal		86	0	—
	Golden Plume		63	1	Fern leaf
Badly malformed	Golden Self-Blanching (tall)	{ 1934	37	0	—
	Winter Queen		52	2	Mottled
	Paris Golden		126	2	Fern leaf mottle
Michigan celery mottle	Golden Plume	{ 1935	68	0	—
	Golden Wonder		62	2	Fern leaf
Western celery mosaic	Michigan Golden		20,000*	0	—
Celery virus I	<u>Commelina communis</u>	1933	110	0	—
	Golden Self-Blanching (tall)	1934	{ 44 350 ✓	2 0	Mottle —
Healthy check	celery				

* Michigan Golden ~~celery~~ selections contracted the disease from escaped ~~viriferous~~ aphids and this seed was used in breeding trials. A close examination of 2,000 plants revealed no mosaic~~ed~~ plants.

✓ Seeds of samples sent from Southern California Seed Company and from same lots that were planted in southern California and became badly mosaic~~ed~~.

matured seed the same year and seedlings were grown the following season. No seed was obtained from plants infected with Celery virus I, but seed was secured from mosaicked Commelinas. The results are summarized in table 2.

The data in the table show that if the viruses are transmitted through the seed, it is a very rare phenomenon. The seedlings were grown in the open field and no precaution, other than an aphidicidal spray applied once a week, was taken to prevent outside infection.

Longevity in Vitro

The rapid death of the virus in unsterilized, unfiltered, expressed sap from most viruliferous plants is probably due to several factors. Some viruses are able to live long periods in vitro at room temperature. The length of life is usually proportional to the storage temperature. It seems desirable to standardize such procedure by using small tubes, definite aliquots, by removal of tissue parts, and by storage at controlled temperatures; but such has not been the practice of most workers. In accordance with the usual practice, and since only comparisons were desired, viruses of this study were stored in ordinary test tubes in the open room. Juice was expressed from typically diseased plants, strained through muslin, and 10 cc. placed in each of 2 test tubes. One tube was placed in a storage basement where the temperature was from 15° to 20° C., and the other was placed in the laboratory where the temperature was 20° to 28° C. Samples were taken as indicated in table 3 and rubbed on 6

TABLE 3

Results of Aging in Vitro of the 4 Viruses Naturally Occurring on Celery

Storage time, hrs.	Celery virus I		Western celery mosaic virus		Celery stem leaf virus		Michigan celery mottle virus	
	20°-28° C.	15°-20° C.	20°-28° C.	15°-20° C.	20°-28° C.	15°-20° C.	20°-28° C.	15°-20° C.
1	—	6	—	6	—	6	—	6
12	—	6	—	6	—	6	—	6
20	6	5	6	5	6	6	6	6
36	6	6	6	5	1	6	2	5
48	4	6	6	6	0	6	0	6
72	1	6	1 (?)	4	0	2	0	1
90	0	4	0	1	0	0	0	0
112	0	2	0	0	0	0	0	0
10 days	0	0	0	0	0	0	0	0

6 healthy broad-leaf tobacco plants. The tabulated data indicate^s the number of plants which became infected.

Although the readings on the death point of each virus were somewhat irregular, the life of the 4 viruses in vitro at the temperature indicated is somewhere between 70 and 110 hours. Celery virus I probably retains its infectivity longer than the other viruses. The Western celery mosaic virus came next, with the other 2 nearly the same. The length of life in vitro of the 4 viruses is apparently too similar to be of differential significance.

Thermal Death Point

Johnson and Hoggan (14, 15) and Johnson (12) have pointed out the value of a determination of the temperature above which a virus, after exposure for 10 minutes, becomes noninfective. The common term applied to this critical temperature in bacteriological and virus studies is "thermal death point" and will be so designated in this study.

In general, the method as described by Johnson and Grant (13) was followed and is described here in its essential details. Small glass tubes 1 mm. inside diameter were cut into 10-cm. lengths. Freshly expressed viruliferous juice was placed in a small vial 10 cm. deep. One of the glass tubes was then inserted into the juice, and by placing the index finger over the exposed end, the tube could be removed with approximately 8 cm. of its length filled. The tube was oriented horizontally and the finger removed to allow an even distribution of the liquid. The finger was

TABLE 4

Results of Exposing to Differential Temperatures for 10 Minutes, Viruliferous Sap Taken from Celery Plants Infected with the Viruses, Respectively, which Occur Naturally on Celery.

The Readings Indicate Number of Plants Which Become Diseased

Temperature, °C.	Cucumber white picket virus	Western celery mosaic virus	Michigan celery mottle virus	Celery fern leaf virus	Celery virus I *
40	4	3	4	3	4
45	5	4	0	4	5
50	3	1	2	1	4
55	1	0	0	0	2
60	0	0	0	0	1
65	0	0	0	0	0
70	0	0	0	0	0
80	0	0	0	0	0
Check	5	5	5	6	5

* Slightly more tolerant to heat than the other viruses but the differences were too slight to be significant.

replaced so as to hold the liquid in place while the ends were dipped in melted wax. Sets of 6 tubes were tied separately at spaced intervals on a string and each set was then exposed to a different temperature by immersion in a water bath for 10 minutes. At the end of the exposure period they were removed and immersed in cold water. The cucumber white-pickel virus was used for comparison. The results are shown in table 4. Each tube of the lot was used to inoculate one young healthy tobacco plant. A small pinch of the powdered carborundum was dusted on the leaf and the contents of one tube emptied into it. With care, an entire lot of 6 tubes can be handled by using separate fingers, respectively, for rubbing each plant between each sterilization of the hands.

The viruses were taken from typically diseased celery plants of the variety Michigan Golden. Juice taken from tobacco plants affected with the same viruses gave essentially similar results.

Host Range

Some of the celery viruses, like many others, have been found to infect a large number of host plants in widely separated genera. Wellman (39, 40) found Celery virus I to be capable of infecting 94 species of plants in 21 families. These host plants occur in families from the Compositae to others in distantly related monocotyledonous families. In fact, Wellman found certain monocotyledonous hosts, such as day flower, and dicotyledonous ones, as ragweed,

to be the most important source. from which the virus spread to celery. Other viruses of this study have been found to be cosmopolitan in their capability of infecting plants in distantly related families.

Since the viruses found on celery are seemingly closely related, as shown by thermal death-point determinations, aging studies, etc., it seemed very important to investigate their host range so that perhaps hosts would be discovered which would give sharper distinctions than the symptoms on celery. Space has limited the work to some extent but the positive results reported here are from a sufficient number of test plants which have displayed certain symptoms. When juice was taken from these plants and inoculated back into celery, the symptoms displayed were specific for that virus. Doubtful cases have been reported as negative.

Celery Virus I

The host range of this virus has been thoroughly studied by Wellman (39, 40), and much of his work has been repeated by the author. In this study, only such phases as are important for comparative purposes are reported. On some hosts the virus produces typical mottle mosaic, such as that produced by the cucumber mosaic virus. It was easily transmitted with the cotton aphid and, although successfully transmitted mechanically by aid of the Rawlins' technique, it was less easily transmitted than the other viruses affecting celery. No plants were successfully inoculated that were not mentioned by Wellman (40). Considerable difficulty was experienced in infecting watermelon, and

in the small percentage of infected plants, symptoms were unlike those reported by Wellman (36). This may have been due to unfavorable growing conditions for the host plant.

The similarity of disease caused by this virus and that caused by the Western celery mosaic virus and the Michigan celery mottle virus has led some authors to regard them as one. In the tests reported here, the inability of Celery virus I to infect bean (Phaseolus vulgaris) and the inability of some of the others to produce characteristic symptoms on bean is considered quite important diagnostically. The following varieties of the ordinary garden bean were inoculated with Celery virus I without producing a single infection: Scotia, Henderson's Stringless Green Pod, Stringless Refugee, and Red Kidney. No local lesions or symptoms of systemic infection were produced, and the virus was not recovered from the crushed primary leaves.

The virus was transmitted to other hosts with aphides and by mechanical means, as shown in table 5. In contrast to Wellman's failure to transmit the virus to Commelina communis by rubbing, the author has obtained a small percentage of infection with the Rawlins technique (fig. 6).



Fig. 6. Commelina communis ~~twigs~~. A, mechanically infected with the southern celery mosaic virus; B, healthy. ~~twig~~.

Western Celery Mosaic

The recent discovery of this virus in California and the serious nature of the disease it produces on celery, will no doubt stimulate investigators to determine its properties, host range, identity, etc. At present the only report of the disease is by Severin and Freitag in which they called it Western celery mosaic and have shown it to be aphid-transmitted. Since the symptoms are different from those of other celery virus diseases, a search was made for differential hosts that will aid in its classification. In the course of this study, the virus has been transmitted both mechanically and with aphides to a number of host plants (see table 5). Since this disease has been described only on celery, its effect on other hosts will be described in some detail.

Solanaceae.—Symptoms of Nicotiana tabacum and N. glutinosa are very similar to those of ordinary tobacco mosaic. No local lesions developed on either host. On N. tabacum the primary symptoms appear in 8 to 10 days after inoculation, in the form of a slight clearing of the veins and a puckering of the interveinal tissue. The new leaves become slightly convex, with a tendency to roll upward along the edges. Two days later, depending on temperature, the disease becomes systemic, with dark and light islands appearing on the leaves. On N. glutinosa the primary symptoms are a typical blanching of the leaves without any flexing. Symptoms on old leaves of N. glutinosa are very

TABLE 5

A Summary of the Infection Experiments with the 4 Viruses Which Occur Naturally on Celery

Host name	Celery virus I	Western celery mosaic virus		Michigan celery mottle virus		Celery fern leaf virus					
		Inoculation infection:									
		A ^{*/}	M [†]	R [†]	A		M	R	A	M	R
<u>Nicotiana tabacum</u>	15 0	30 25	+	15 0	40 40	+	10 0	40 36	-	40 29	+
<u>N. glutinosa</u>	-	15 6	+	-	15 14	+	-	15 11	-	15 9	+
<u>Lycopersicum esculentum</u> (tomato)	-	20 6	+	-	20 19	+	-	20 20	-	20 8	+
<u>Physalis pubescens</u> (ground cherry)	-	10 10	-	-	10 8	-	-	10 9	-	10 10	-
<u>Capsicum annuum</u> (pepper)	-	12 10	+	-	8 5	+	-	8 3	-	15 15	+
<u>Apium graveolens</u> var. dulce (celery, self- blanching)	20 19	68 25	+	80 79	60 60	+	60 57	50 49	35 26	60 34	+
<u>Daucus carota</u> (carrot)	-	-	-	10 10	17 8	+	-	10 0	-	10 0	-
<u>Coriandrum sativum</u> (coriander)	-	-	-	10 6	5 3	+	-	10 0	-	10 0	-
<u>Anethum graveolens</u> (dill)	-	-	-	10 10	-	+	-	10 10	-	10 10	-
<u>Phaseolus vulgaris</u> (bean, var. Scott's)	-	10 0	-	-	10 10	+	-	24 21	-	10 10	-
<u>P. vulgaris</u> (bean, var. (Stringless Refugee)	-	10 0	-	-	10 7	?	-	20 20	-	20 0	-
<u>P. vulgaris</u> (bean, var. Burpee Stringless (Green Pod)	-	10 0	-	-	10 10	+	-	10 9	-	10 0	-
<u>Cucumis sativus</u> (cucumber)	-	20 12	+	-	20 20	+	-	20 17	-	45 42	+
<u>Spinacia oleraceae</u> (spinach)	-	10 9	+	-	20 20	+	-	12 12	-	10 7	+
<u>Commelina communis</u> (wild wandering jew)	12 10	20 3	+	10 0	10 0	-	-	10 0	10 3	10 0	+
<u>Zea mays</u> (sweet corn)	25 3	25 2	+	20 0	20 0	-	10 0	10 0	10 0	10 1	+

* A indicates aphid inoculation; † M indicates mechanical inoculation; ‡ R refers to recovery

similar to those on N. tabacum. These are dwarfing and a true mottling, with the occurrence of dark-green and blister-like islands unaccompanied by necrosis. N. glutinosa may develop some filiformities under poor light conditions. Symptoms on these 2 species are very variable, depending on light, temperature, etc. Only the presence or absence of such symptoms as local lesions, necrosis, rings, streaks, or other similarly clear-cut symptoms should be given much consideration in diagnosis.

On tomato (fig. 7) the virus produces very little mottling but tends to cause leaf elongation with awn-like tips. These seem to be quite uniform and are unlike the fern-leaf and shoe-string effects of cucumber mosaic. The plants are much dwarfed and show some vein-clearing similar to that which is characteristic of the primary symptoms on celery.

Ground cherry (Physalis pubescens) developed symptoms in 8 to 10 days after inoculation and reacted very similarly to N. glutinosa. Datura stramonium developed whitish local lesions on the inoculated leaves similar to those described by Wellman (36) for Celery virus I but the infection never became systemic.

Umbellifereae.--Infection on celery has been described under a previous section, and need not be described further. Dill (Anethum graveolens), carrot (Caucus carota), and Coriander (Coriandrum sativum) were infected with the Western celery mosaic virus. The virus was transferred to the carrot and dill plants by the cotton aphid which previously had been colonized



Fig. 7. Bonny Best tomato leaves. Right, artificially infected with the Western celery mosaic virus; left, normal. ~~leaves.~~

on a diseased celery plant. All the plants were yellowed and dwarfed. Coriander was infected mechanically and became quite bushy with vein-clearings on the broader leaves. Dill also became quite bushy; the dwarfed appearance was due to shortened internodes and caused the small leaves to appear very thickly placed. On carrot the leaves were shortened and the ends of the ultimate divisions were twisted and mottled.

Leguminosae.—Price (21,22) has shown that the Scotia bean forms necrotic lesions as a local reaction when the primary leaves are rubbed with sap from plants affected with severe tobacco virus. The simple leaves of this variety were rubbed with juice from a typically mottled celery plant affected with Western celery mosaic, using Rawlins' technique. After 20 days no local reaction was evident, but the virus had become systemic. The initial symptoms were vein-clearings along the main and lateral veins. Later, the clearings became more prominent and, on the upper surface, appeared as furrows which varied in depth with the size of the veins (fig. 8). Similar symptoms developed on the variety Henderson's Stringless Green Pod. Secondary leaves, which developed on plants of this variety in which the virus had become thoroughly established, became somewhat savoyed and displayed symptoms similar to those described on Stringless Refugee by Nelson (18). No symptoms were observed which were typical of ordinary bean mosaic, as described by Pierce (19).

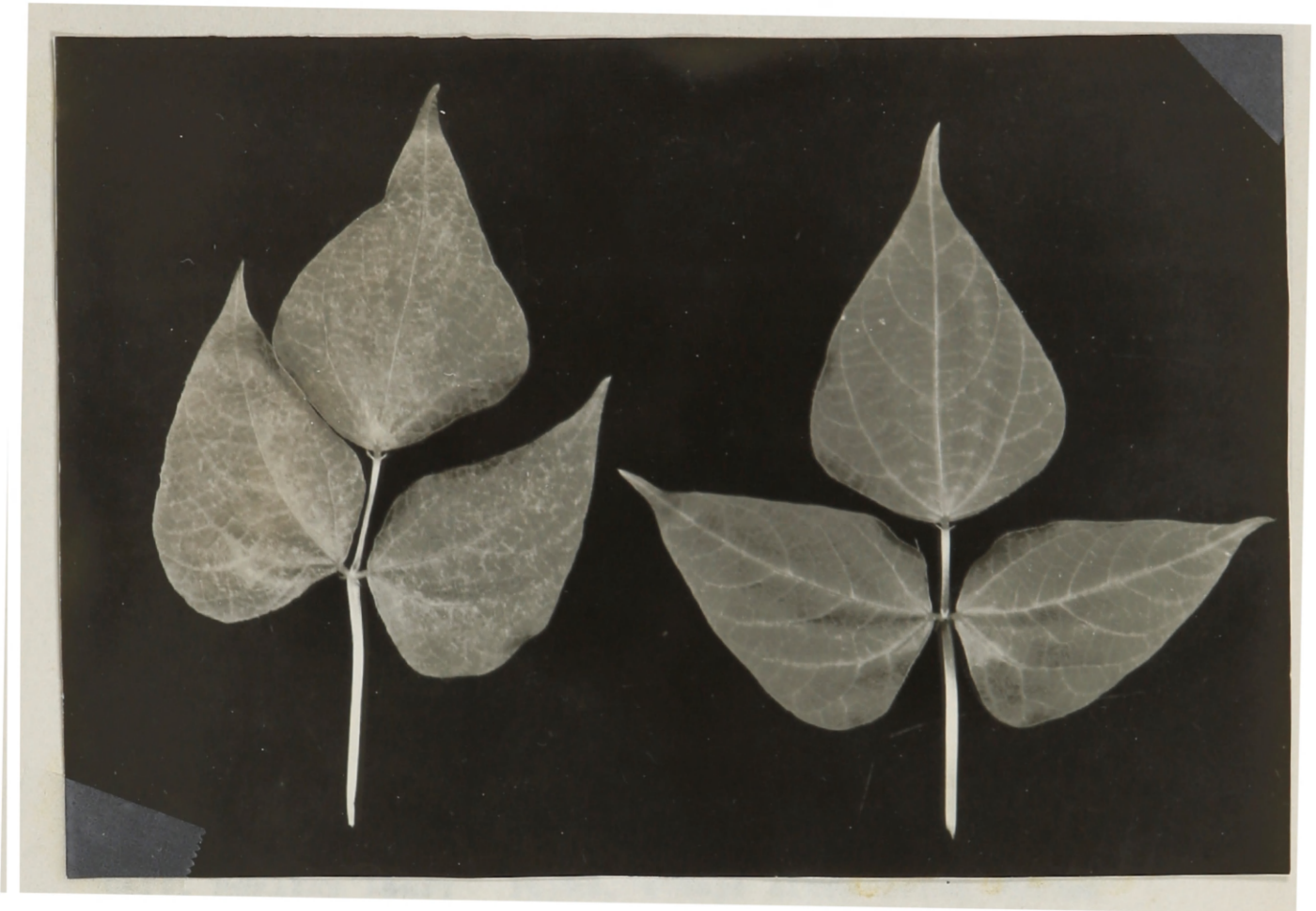


Fig. 8. Bean leaves of the variety Scotia. Left, artificially infected with the Western celery mosaic virus; right, normal ~~leaves~~.



Fig. 9. Primary leaves of the Scotia bean.
Left, healthy leaf; right, 4 days after being rubbed
with powdered carborundum in expressed juice from celery
affected with Michigan celery mottle.

Other Hosts.—On cucumber, infection resulted in symptoms which resembled typical cucumber mosaic. White-spine cucumber seedlings were inoculated on the cotyledon~~ary~~ leaves, using Rawlins' method, and after 10 days the first secondary leaf showed patchy mottling. No local lesions were observed. After 20 days, 30 per cent of the inoculated plants were dead and the remainder were dwarfed. No fruits were produced and thus no comparisons could be made with the fruit symptoms of white pickle mosaic.

Ordinary garden spinach was easily infected with the Western celery mosaic virus and produced a typical flavescent mosaic. Seedlings inoculated on the cotyledons were yellowed in 6 days. Older plants inoculated on the third and fourth leaves yellowed in 6 to 8 days, and this was followed by drooping of the extended leaves. Although the leaves were turgid, they appeared as if they were suffering from lack of water. This was followed by a general chlorosis and a mottling, but with very little leaf malformation. A high percentage of the plants developed stem necrosis and died within a few weeks.

Plants Inoculated But Not Infected.—Both aphides and mechanical methods gave negative results in the transfer of the Western celery mosaic virus to the following: Brassica rapa (turnip), B. oleracea capitata (cabbage), Commelina communis (wild wandering Jew), Pastinaca sativa (parsnip), Petroselinum hortense (plain parsley), Zea mays (sweet corn), Citrullus vulgaris (watermelon),

Sambucus canadensis (blackberried elder), and Malva sp.
(a wild malva from California.)

Michigan Celery Mottle

Umbelliferae.—Symptoms of the disease on celery produced by the Michigan mottle virus have been described earlier in this paper, and they are repeated here for comparative purposes only. The fact that only the mature leaves are mottled suggests that this virus is entirely different from the others. The leaf-mottling corresponds well with the celery calico reported by Severin and Freit~~ag~~ (26) from California and which they think is distinct from the Western celery mosaic. With this suggested distinction in symptoms it seemed desirable to search for differential host plants. A number of plants were infected and some of these developed symptoms which will be described in some detail. Experimentally, in view of the fact that differential characteristics on celery occur only on the old leaves, and the lack of vigorous dwarfing, the reading of results is complicated by the necessity of growing plants to semimaturity. A complete list of plants which become infected is given in table 6.

Coriander, carrot, dill, parsley, and parsnips were inoculated with negative results. It is quite possible that infection may have occurred and poor light conditions obscured visible symptoms.

Solanaceae.—Both Nicotiana tabacum and N. glutinosa were successfully inoculated by means of Rawlins' technique. No local lesions or necrotic reactions were noted. Initial

symptoms appeared in 10 days as angular, dark-green blisters on the paler leaves. These symptoms are intensified with further growth and appear similar to the mottle symptoms of ordinary tobacco mosaic. There was a slight tendency toward foliar elongation on N. glutinosa, but no malformation on N. tabacum. Plants systemically infected showed no tendency to mask or outgrow the symptoms.

Tomato developed symptoms in 8 to 10 days after inoculation. Young leaves were noticeably narrowed but not shoe-stringed, and they formed no acute tips on their ultimate segments, but they lacked the long awn-like appendages which developed on plants affected with the Western celery mosaic virus. Older leaves were narrower than healthy ones and developed a mottle similar to ordinary tomato mosaic.

Physalis pubescens was infected as easily as tomato and became similarly mottled.

Leguminosae.--Three varieties of beans (Phaseolus vulgaris) were inoculated in the usual way with juice from typically mottled celery plants and infection resulted on two. Ten-day-old seedlings of the variety Scotia inoculated on the primary leaves developed numerous local lesions after 4 days (fig. 9). Fifteen days later the virus had become systemic and produced a random angular mottling (fig. 10). No cupping or malformation of the leaves characteristic of ordinary mosaic was observed. Seeds from infected plants have not been tested for transmission. Burpee's Stringless Green Pod developed no local lesions but became slightly mottled. Attempts to recover the virus from this latter variety failed. Stringless Refugee was inoculated

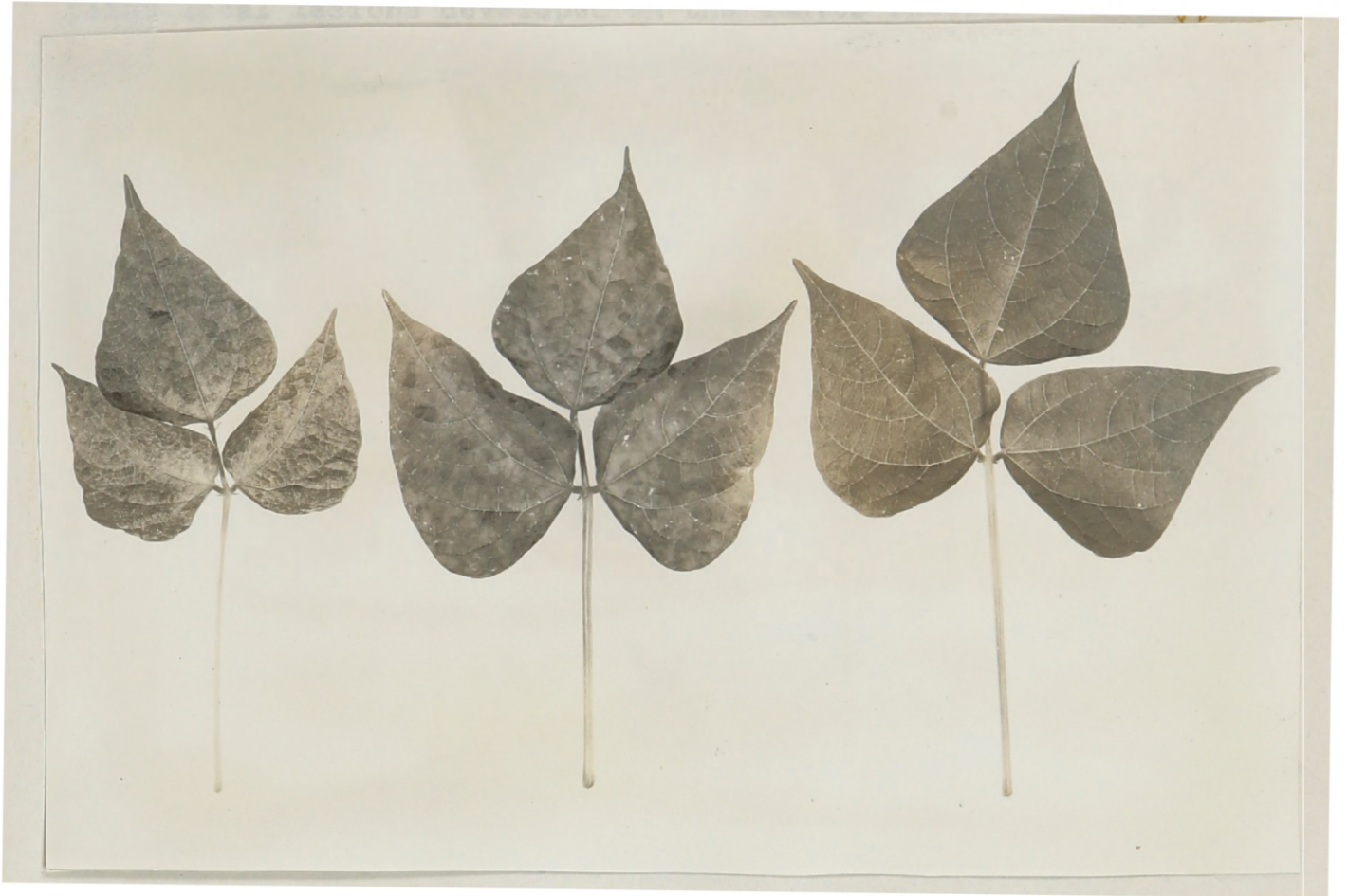


Fig. 10. Secondary leaves of Scotia bean.
A and B show angular type of mottle 20 days after the primary leaves had been rubbed with the Michigan celery mottle virus; C, normal leaves of same age.

as above with the celery mottle virus, and for comparison a similar series was inoculated with tobacco ring spot and typical bean mosaic virus. Four days later numerous pin-point local lesions developed on the leaves inoculated with the Michigan celery mottle virus and the Typical bean mosaic virus (fig. 11). Beans inoculated with Tobacco ring spot virus developed diffusely angular lesions on their primary leaves after 10 days. ^{Slight} ~~A few twisted~~ symptoms of systemic infection occurred. These inoculations were made in December and light conditions were very poor. All three of the viruses mentioned above as producing local lesions on Refugee bean were recovered from the crushed primary leaves of their respective infected plants.

Cowpea (Vigna sinensis) and peanut (Arachis hypogea) were inoculated but no infection occurred.

Other Hosts.—Infection was easily produced on white spine cucumbers. Seedlings inoculated on the cotyledons by Rawlins' technique developed a coarse mottling accompanied by a stunting, but no necrosis or malformation was observed. Garden spinach was artificially infected and reacted very similarly to plants infected with the Western celery mosaic virus. Leaves became convexed and turned downward. After 2 weeks most of the plants developed stem necrosis and died.

The following plants failed to develop symptoms when artificially inoculated: Daucus carota (carrot), Anethum graveolens (dill), Coriandrum sativum (Coriander), Petroselinum hortense (plain parsley), Pastinaca sativa (parsnip),

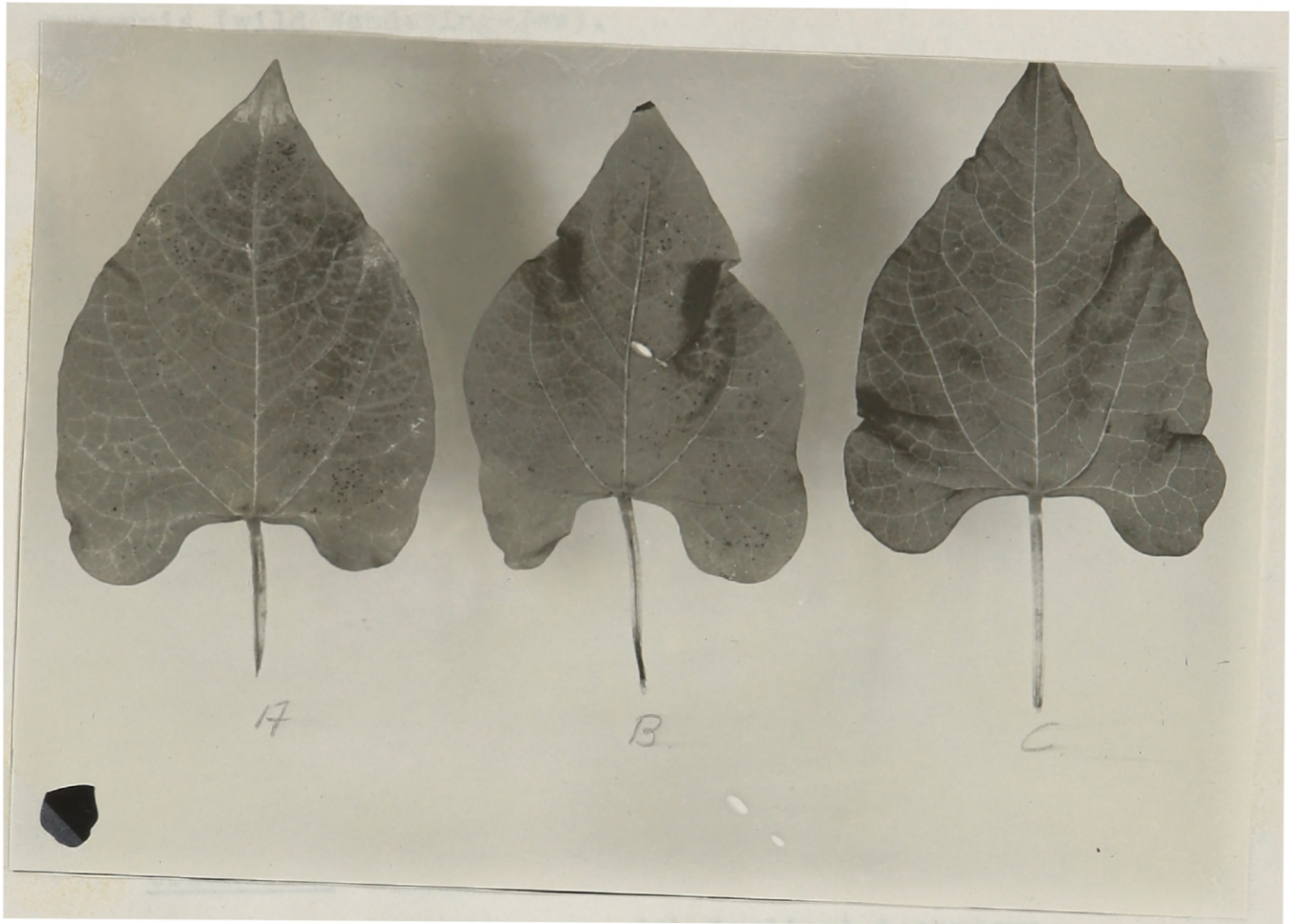


Fig. 11. Primary leaves of Refugee bean.

A shows pinpoint lesions 5 days after being rubbed with juice from young bean plants affected with ordinary bean mosaic; B, similar to A, except that they were rubbed with juice from a celery plant affected with Michigan celery mottle; C, normal leaf.

Brassica rapa (turnip), B. oleracea capitata (cabbage),
Citrullus vulgaris (watermelon), Zea mays (sweet corn),
Sambucus canadensis (blackberried elder), and Commelina
communis (wild Wandering-Jew).

Celery Fern Leaf

This type of mosaic was first described by Poole (20) and has since been attributed to cucumber mosaic virus by Wellman and others (36, 13).

Umbelliferae.—Sufficient description under "Symptoms on Celery" has already been given for comparisons in this paper. The distinguishing characteristic of the trouble is the pinching, savoying, and malformation of the leaves, with little or no mottling. Some plants have been observed in the field which were both mottled and fern-leaved and, although not investigated, were thought to be infected with 2 viruses. No infection was obtained on other species of Umbelliferae.

Solanaceae.—Nicotiana tabacum and N. glutinosa were easily infected by rubbing or with Rawlins' technique. Symptoms differed from those produced by the other viruses affecting celery in that, in addition to ordinary mosaic symptoms, many of the leaves were blistered and malformed. On N. tabacum some leaves were reduced to mere ribbons; others greatly narrowed and constricted in the middle, resulting in asymmetry. Initial symptoms developed in 6 to 8 days and became evident as flavescent tips on the first and second leaves succeeding the inoculated leaves. This paling



Fig. 12. Leaves of *Nicotiana tabacum*. A and B show initial paling of the tips of heart leaves 6 days after ^{inoculation} ~~having been infected~~ with juice from celery plants affected with fern leaf; C, normal leaf.



Fig. 13. Left, tomato plant 20 days after being rubbed with juice from celery affected with fern leaf. The rubbing was done on fully expanded cotyledon leaves; right, top of normal plant of same age.

progressed as the leaves developed (fig. 12) and was followed by blister-like erumpent areas in the lamina. Older leaves were markedly malformed; some were ribbon-like; others were constricted on one side and asymmetrical. Infected N. glutinosa plants resembled those of N. tabacum but they tended to produce more of the ribbon and hair leaves. Plants of both species infected in the summer were less malformed than those infected during the winter.

Physalis pubescens was readily infected, and after 6 days showed slight pinching at the tip of the first succeeding leaf above the inoculated one. Symptoms on older leaves were similar to those produced on N. glutinosa. Some leaves became cylindrical and filiform and approximated the size of the lead in a lead pencil.

On tomato, true fern leaf, as described by Morgendorff (17), developed (fig. 13). Infected seedlings were slightly yellowed after 6 days, and at the end of 12 days had developed malformations in the heart leaves. Infected plants remained very small.

On pepper, the initial symptoms of the virus were stunting and etching. As the leaves aged, some became yellow and dropped from the plant.

Other Hosts.—White spine cucumber and spinach were infected with the Celery fern leaf virus. Seedling cucumbers were inoculated on the cotyledons, and after 10 days the primary leaf became sharply flexed toward the stem so that the lamina was perpendicular to the surface of the soil

and parallel to the axis of the plant. As soon as symptoms first became evident, growth was greatly retarded. The plants developed only a half dozen leaves in 6 days, some of which were strongly mottled. Small clusters of flowers developed at the nodes but no fruits were formed, and no comparisons could be made with the fruit symptoms of the white pickle virus. The general symptoms on the seedling were very similar to those described for the white-pickle virus by Doolittle (1).

Spinach became slightly yellowed after 8 days and the leaves were cupped downward. Older plants developed sundrious filiformities very similar to those described by Hoggan (10) when she produced spinach blight with Cucumber virus I.

A small percentage of infection was obtained on Commelina communis. The leaves developing after infection were narrow and slightly striped with green (fig. 14).

Infection of Celery With Other Viruses

Several known viruses were obtained from various sources, as shown in table 1, and were used in a study of the susceptibility of celery. Some of these have been shown to infect celery, and comparisons have been made with the naturally occurring viruses on celery. In the following paragraphs a description of some of the symptoms produced by some of these viruses on celery is summarized.



Fig. 14. ~~Twigs of~~ Commelina communis. A and B infected with the celery fern leaf virus and showing filiformities with slight etching and streaking; C, normal ~~twigs~~.

Cucumber Virus I.—The Cucumber virus I, or white-pickle virus, as described by Doolittle (1), was obtained from him and used to infect celery. Young plants were inoculated on the fifth leaf by the Rawlins method, and after 12 days they showed definite indications of infection. Leaflets of the heart leaves were strongly convexed but the rachises were normal. This differs from initial symptoms ^{caused by} ~~of~~ Celery virus I in which the rachises are obliquely curved downward. After 24 days the infected celery plants developed various malformities, from ruffled foliage to shoe-string leaflets. The symptoms were identical with those of the celery fern leaf disease. These results agree with those reported by Wellman (36) from which he suggests the identity of Poole's celery mosaic and that caused by Cucumber virus I.

White-pickle mosaic obtained from naturally infected cucumber plants growing in the college plots was used to inoculate celery. Symptoms identical with those produced by the Doolittle virus developed, and the viruses appear to be identical.

A culture of Cucumber virus I was obtained from Johnson and inoculated ~~on~~ to celery. Initial symptoms became evident after 8 days as chlorosis in definite patterns (fig. 15). There was no downward cupping of the leaves, such as is produced by the local cucumber virus and by the one obtained from Doolittle. After 15 days, heart leaves became convexed with pronounced chlorosis of the veins (fig. 15). Plants set in cold frames developed rugose and shoe-string leaves without mottling or necrosis.



Fig. 15. Leaves from young celery plants. A and B from plant inoculated with cucumber virus I obtained from J. Johnston. A shows mottle which developed 8 days after ~~being rubbed~~ ^{inoculation}; B, heart leaf from a longer-infected plant; C, normal.

As a result of the cross inoculations from cucumber to celery and from celery to cucumber, the similarity of symptoms supports the suggestion of Wellman of the identity of the Celery fern-leaf virus with Cucumber virus I. The only explanation for the difference in reaction of the Johnson culture is that there may be different strains of the cucumber virus.

Tobacco Ring Spot.—Wellman (36), Walker (31), and Johnson and Grant (13) infected celery with the Tobacco ring-spot virus. Tobacco leaves infected with this virus ~~and~~ collected from a commercial field in Kentucky were obtained by the author from Valleau. Inoculations were made on celery with the Rawlins method, and after 11 days the heart leaves were noticeably paler. On the twelfth day the leaflets were cupped downward and the chlorosis of the veins was more marked. Plants which were set in beds and allowed to mature developed malformations similar to those produced by the cucumber virus but they were less severe.

Spotted. Wilt.—Gardner, Tompkins, and Whipple (7) reported infection of celery with the spotted wilt virus in California and described the symptoms produced. For comparative purposes the author obtained a culture of the virus on calla lily from Gardner and inoculated it onto celery. After 20 days, chlorotic flecks developed on the inoculated leaves. Ten days later the celery plants were uniformly mottled and the original chlorotic areas became necrotic (fig. 16).



Fig. 16. Michigan Golden celery leaves. A and B infected with the spotted wilt virus. A, leaf on which rubbing was done, showing the initial local lesions which have become necrotic; B, heart leaf showing systemic infection from the same plant.

Aster Yellows.—Severin (24, 25) reported infection of ^{the} aster yellows ^{virus} on celery. Kunkel, earlier, had failed to transmit this disease to celery. Later he obtained Severin's strain of the virus with which he was able to produce infection on celery (16). Gardner ^{*} reports this virus as becoming widespread and more serious in California. It is apparent that the strain of aster yellows virus in Michigan is not the one capable of infecting celery.

Other Viruses Tried.—Bean mosaic virus obtained from seedling Refugee bean plants and tobacco mosaic virus obtained from Valteau gave negative results when inoculated on celery.

A Key to the Viruses Affecting Celery

- A. Celery petioles and leaves twisted; slight to pronounced local or general chlorosis; not transmissible mechanically to broad-leaf tobacco Aster yellows virus.
- A. Mechanically transmissible to broad-leaf tobacco.
 - B. Leaflets chlorotically measled, necrotic spots on leaves; produces large local lesions on tobacco Spotted wilt virus.
 - B. Mottling without local lesions on tobacco.
 - C. Mechanically transmissible to bean (Phaseolus vulgaris var. Scotia).
 - D. Produces local lesions when rubbed on primary leaves.

^{*} Information from conversation with M. W. Gardner.

- E. Typical ring-spot necrosis
on broad-leaf tobacco. . . .
Tobacco ring spot.
- E. Only mottling on broad-leaf
tobacco . . . Michigan celery
mottle.
- D. Systemic infection on Scotia bean
without local lesions
Western celery mosaic.
- C. No infection on bean.
 - F. Marble-like mottling and
petiolar necrosis on self-
blanching celery
Celery virus I.
 - F. Malformations and fili-
formities on celery,
rarely mottling
Celery fern leaf or Cucum-
ber virus I.

DISCUSSION AND SUMMARY

The studies here reported have distinguished 4 viruses which occur naturally on celery. All of these viruses have been previously reported but their geographic distribution and the incomplete descriptions in the literature of some have caused some confusion. A description of symptoms of certain other known viruses which are able to infect celery, and some of which have been reported heretofore, is brought under one head.

Wellman's studies (36) have left little doubt as to the distinctness of the southern celery mosaic caused by Celery virus I. Wellman, from descriptions in the literature and from specimens examined, has noted similar symptoms on celery from California, Wisconsin, Ohio, and New York, but he does

not associate these with his Celery virus I. Wellman's (36) distinction of the Celery virus I from Tobacco virus I, Tobacco ring-spot virus, and Cucumber virus I is quite clear. In accordance with his deductions and in view of data present in this study, the author is inclined to agree that Celery virus I is limited to the subtropics and tropics.

Certain physiological properties of the viruses, such as thermal death point and length of life in vitro were studied and no marked differences were found. All the viruses were found to be both aphid and mechanically transmissible. Certain symptoms on celery were noted and considered distinctively clear-cut. A number of other plants were infected, some of which serve as differential hosts.

Western celery mosaic virus obtained from California from Gardner, Kendrick, and Nelson is different from Wellman's Celery virus I. Western celery mosaic is readily transmitted to bean (Phaseolus vulgaris var. Scotia and Burpee's Stringless Green Pod), while numerous inoculations with Celery virus I confirmed the negative results of Wellman. Although the leaf mottling produced by each is somewhat similar, the general symptoms on celery are considerably different. Celery virus I usually produces necrotic areas on or at the base of the petiole, while the Western celery mosaic virus produces no necrosis on celery. The Western celery mosaic virus produces initial symptoms of vein chlorosis without cupping of the leaves or downward curvature of the petioles. These early symptoms are entirely

unlike those produced by Celery virus I. The symptoms on older celery plants are difficult to distinguish, except that the petioles of plants infected with the Western virus are characteristically mottled with longitudinal splotches; the leaves are affected with a general chlorotic mottle and there is considerable downward cupping. The leaf mottling on plants infected with Celery virus I is very brilliant and there is little petiolar mottling. In the light of the reactions of other viruses on celery, the author is inclined to place more emphasis on the diagnostic value of the petiolar necrosis caused by Celery virus I. Plants infected with the Western celery mosaic virus of this study were sent to Severin (26) for comparison with his Western celery mosaic. He states that they are identical.

Michigan celery mottle is distinct from the diseases caused by Celery virus I and the Western celery mosaic virus. In the field the virus produces discontinuous patterns on the older or fully expanded leaves, with comparatively little stunting, as compared with the general stunting and brilliant mottle caused by Celery virus I and the stunting and general mosaic caused by the Western celery mosaic virus. Physiological studies did not reveal any consistent differential characteristics. Inoculation of beans (Phaseolus vulgaris var. Scotia and Burpee's Stringless Green Pod) produced local lesions on the simple leaves (fig.), a test which gives sharp distinction from Celery virus I and the Western celery mosaic virus. The Michigan celery mottle virus produces systemic

infection on Scotia bean, but the symptoms are unlike those of ordinary bean mosaic. Ordinary bean mosaic was not transmitted to celery. There are certain similarities between Michigan celery mottle and Severin's (26) celery mottle, but plants have not been exchanged, and his description is insufficient for identification.

The malformities produced by the Celery fern-leaf virus are so distinctly different from symptoms produced by the other viruses on celery that this characteristic alone identifies this virus. The production of similar symptoms on celery by Cucumber virus I suggested to Wellman the identity of this virus and the Celery fern-leaf virus. This work has been repeated by the author with Cucumber virus I from several sources, with similar results. The physiology of the Celery fern-leaf virus agrees with that of Cucumber virus I. It is quite possible that other strains of the cucumber virus may react differently. Cucumber virus I, obtained from Johnson, produced atypical initial symptoms but they later became characteristic.

Several other viruses previously identified on other plants are able to produce infection on celery. These can be readily identified by well-described characters and tests. From descriptions, Harvey's mosaic on celery most nearly approximates the Michigan celery mottle. Elmer, in his mosaic transmission work with celery, undoubtedly was working with the cucumber virus, and from his descriptions he may have had a mixture of 2 viruses. Poole's mosaic of celery is undoubtedly identical with that produced by Cucumber virus I.

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