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APHID TRANSMISSION OF CAULIFLOWER-MOSAIC VIRUS

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THE MOST IMPORTANT SPECIES OF APHIDS ATTACKING CRUCIFEROUS CROPS IN CALIFORNIA

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APHID TRANSMISSION OF CAULIFLOWER- MOSAIC VIRUS¹

HENRY H. P. SEVERIN² and C. M. TOMPKINS³

SUMMARY

ELEVEN SPECIES OF APHIDS that do not multiply on cauliflower plants in nature were demonstrated to be vectors of the cauliflower-mosaic virus, five of them being more efficient vectors than three aphid species that do breed on cauliflower.

Of three aphid species that breed on cauliflower under natural conditions, the cabbage aphid, *Brevicoryne brassicae* (Linnaeus), was a more efficient vector of the virus (in single-insect tests) than the turnip or false cabbage aphid, *Rhopalosiphum pseudobrassicae* (Davis), and the green peach aphid, *Myzus persicae* (Sulzer).

Natural infectivity of the cabbage aphid was demonstrated.

None of twenty-one varieties of cauliflower experimentally infected with the virus by the cabbage and green peach aphids was resistant to the disease.

Mechanical inoculation was more efficient than transmission by the cabbage, turnip, or green peach aphid.

In tests with hourly transfers, most transmissions occurred within 2 hours after the aphids had fed on a mosaic-infected plant.

Aphids acquired the virus in 15 to 25 minutes on a diseased plant (5 to 10 minutes actual feeding time) and transmitted it in feeding periods as short as 5 or 10 minutes. In tests with short feeding periods, most of the transmissions occurred during the first 10 minutes after transfer from the infected plant, but an occasional aphid transmitted the disease during the second or third 10-minute period.

The cabbage and green peach aphids recovered the virus from inoculated cauliflower plants many days before the first symptom appeared.

Mechanical inoculation of healthy cauliflower seedlings and annual stock plants with the centrifuged virus extract from crushed, infective cabbage aphids produced 18 per cent infection.

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INTRODUCTION

Cauliflower is naturally infected with cauliflower mosaic in California (Tompkins, 1934a)⁴ and in Oregon (Tompkins, 1937). Cauliflower plants have been experimentally infected with cauliflower-mosaic virus by mechanical inoculation (Tompkins, 1934a). The host range and properties of the virus have been reported (Tompkins, 1937).

Cauliflower-mosaic virus is transmitted by the cabbage aphid, *Brevicoryne brassicae* Linnaeus, and the green peach aphid, *Myzus persicae* (Sulzer) (Tompkins, 1934a, 1937). Keicola (1945) demonstrated that *M. persicae* and *B. brassicae*, when colonized on cauliflower seedlings infected with both cabbage black ringspot (cabbage ringspot) and cauliflower mosaic, transmitted both viruses; whereas *M. ornatus*, when similarly colonized, transmitted only the cauliflower-mosaic virus.

An investigation was undertaken to obtain further information on aphid transmission of the cauliflower-mosaic virus. Tests were made both with species that do not breed on cauliflower under natural conditions and with species that do. Other aspects investigated include the efficiency in the transmission of the virus by single aphids and by varying numbers of aphids; susceptibility of cauliflower varieties to the disease; comparative efficiency of mechanical inoculation and aphid transmission; the natural infectivity of the aphids; retention of the virus by aphids; and whether infections could be obtained with the virus extract from crushed, infective aphids.

In a companion paper, Essig (1948) discusses the characters, distribution, and food plants of aphid species which occur on cauliflower plants under natural conditions in California.

Leafhoppers transmit two other viruses to cauliflower: cauliflower plants experimentally infected with the curly-top virus by means of the beet leafhopper, *Eutettix tenellus* (Baker), developed symptoms, though noninfective leafhoppers failed to recover the virus (Severin, 1929); and California aster yellows has been recovered from naturally infected cauliflower and transferred to healthy aster and celery plants by previously noninfective aster leafhoppers, *Macrostelus divinus* (Uhler) (Severin and Frazier, 1945). Hence, tests of cauliflower-mosaic virus transmission by species of leafhoppers were included in this investigation. Transmission by a plant bug naturally occurring on cauliflower was also tested.

MATERIALS AND METHODS

The virus was obtained from severely stunted plants of the February variety of cauliflower at Alvarado. It was maintained by repeated mechanical inoculation and aphid transmission of the virus to healthy February cauliflower and Fiery Blood Red annual stock plants. The carborundum method (Rawlins and Tompkins, 1936) was used in mechanical inoculations.

Colonies of noninfective aphid species were started by transferring mature, wingless aphids from cauliflower, cabbage, or stock to Esmarch dishes with the bottoms covered with moist filter paper. The young aphids were then placed on healthy cauliflower or annual stock plants grown from seeds. The

⁴ See "Literature Cited" for citations, referred to in the text by author and date.

method of transferring aphids has been published in a previous paper (Severin and Freitag, 1938). The preparation of the virus extract from crushed, infective aphids and by centrifugation was similar to the method described for the beet leafhopper (Severin and Freitag, 1933).

Fig. 1. Local symptoms of cauliflower mosaic on leaves of cauliflower seedling, on which the cabbage aphid had fed, showing chlorotic areas around mouth-part punctures.

SYMPTOMATOLOGY

A general description of the symptoms of cauliflower mosaic on several host plants including annual stock was given in a previous paper (Tompkins, 1937) : clearing of the veins was the predominant symptom; stunting was not observed. The average incubation period of the disease on Fiery Blood Red annual stock (*Mathiola incana* var. *annua*) was 70 days.

In cauliflower, mosaic is characterized by stunting of the plant, dwarfing of the terminal head or curd, and the following leaf symptoms: vein clearing (plate 1, *B*) ; curvature of the midrib (plate 1, *D*) ; necrotic lesions (plate 1, *E*, *F*) and distortion of the leaf (plate 1, *G*).

Feeding by the cabbage aphid causes symptoms on cauliflower, aside from those caused by the virus. The leaves of cauliflower seedlings on which either noninfective or infective cabbage aphids had fed showed circular chlorotic areas around the mouth-part punctures (fig. 1). The newly developing leaves on which no aphids had fed failed to show this symptom; hence the effect is local and not systemic. Other species of aphids do not cause this symptom.

Since annual stock has been experimentally infected with five crucifer viruses (Tompkins, 1934b, 1937, 1938, 1939; Tompkins, Gardner, and Thomas, 1938), a detailed description of the successive foliage symptoms of cauliflower mosaic on stock is given to distinguish this virus disease from others, especially from mild and severe mosaics of stock plants, described in a previous paper (Tompkins, 1939). The first symptom that appears on the youngest leaves of Fiery Blood Red annual stock is a clearing of the veins and veinlets (plate 2, *C*), followed by the development of numerous chlorotic, circular areas (plate 2, *D*), producing a mottled effect (plate 2, *E*). The veins may protrude on the lower surface of the leaf (plate 1, *F*). A shortening of the internodes occurs, and secondary shoots develop with dwarfed leaves cupped inward along the midrib (plate 2, *A*).

TESTS WITH PLANT BUGS AND LEAFHOPPERS

Tests were made to determine whether plant bugs and leafhoppers occurring in cauliflower fields could transmit the virus of cauliflower mosaic. The harlequin cabbage bug, *Murgantia histrionica* (Hahn), was abundant on cauliflower plants in San Pablo. Lots of 2 to 5 adults were transferred, alternating daily from mosaic to healthy cauliflower plants. No infections occurred with 30 cauliflower plants tested. No infections were obtained with the beet leafhopper, short-winged and long-winged aster leafhoppers, *Macrostelus divisus* (Uhler); the geminate leafhopper, *Colladonus geminatus* (Van Duzee); or the mountain leafhopper, *C. montanus* (Van Duzee).

APHID TRANSMISSION OF VIRUS

By Vectors That Do Not Breed on Cauliflower. Aphids that have not been found to breed on cauliflower plants under natural conditions were tested for transmission of the virus of cauliflower mosaic. The aphids were transferred singly, directly from diseased plants to healthy cauliflower seedlings, one aphid to a plant, and were kept on the healthy plants until they died. Most of the species tested proved capable of transmitting the virus (table 1). There was a considerable variation in the percentages of virus transmission by the different species. The most important vectors were the pea aphid, *Macrosiphum pisi* (Kaltenbach); celery aphid, *Aphis apii* Theobald;⁵ lily aphid, *Myzus circumflexus* (Buckton); and yellow willow aphid, *Cavariella capreae* (Fabricius). Others that transmitted the virus were the celery leaf aphid, *Aphis apigraveolens* Essig; rusty-banded aphid, *Aphis ferruginea-striata* Essig; cotton or melon aphid, *Aphis gossypii* Glover; erigeron root aphid, *Aphis middletonii* (Thomas); foxglove aphid, *Myzus solani* (Kaltenbach); and honeysuckle aphid, *Rhopalosiphum conii* (Davidson). The bean or dock aphid, *Aphis rumicis* Linnaeus, failed to transmit the virus. It may be possible that species of winged aphids play an important role in the dissemination of the virus.

By Single Aphids Breeding on Cauliflower. Three aphid species that breed on cauliflower under natural conditions were tested for efficiency as vectors of the virus; these were the cabbage aphid, *Brevicoryne brassicae* (Linnaeus);

⁵ According to E. O. Essig (personal interview), *Aphis apii* Theobald may be identical with *A. helianthi* Monell.

turnip or false cabbage aphid, *Rhopalosiphum pseudobrassicae* (Davis); and green peach aphid, *Myzus persicae* (Sulzer). Tests were made with wingless and winged aphids, reared to maturity on mosaic-infected cauliflower and then transferred, each to a separate healthy cauliflower plant. Table 2 compares the number of infections obtained with single winged and wingless aphids. Of the three species of aphids tested singly, the cabbage aphid is the most efficient vector of the virus.

TABLE 1
TRANSMISSION OF CAULIFLOWER-MOSAIC VIRUS BY
SINGLE APHID SPECIES

Species of aphids	Cauliflower		Per cent infected
	Inoculated	Infected	
Celery leaf aphid, <i>Aphis apigraveolens</i>	35	2	6
Celery aphid, <i>Aphis apii</i> *.....	35	25	71
Rusty-banded aphid, <i>Aphis ferruginea-striata</i>	85	4	5
Cotton or melon aphid, <i>Aphis gossypii</i>	50	2	4
Erigeron root aphid, <i>Aphis middletonii</i>	75	1	1
Bean or dock aphid, <i>Aphis rumicis</i>	80	0	0
Yellow willow aphid, <i>Cavariella capreae</i>	35	20	57
Pea aphid, <i>Macrosiphum pisi</i>	35	30	86
Lily aphid, <i>Myzus circumflexus</i>	35	23	66
Foxglove aphid, <i>Myzus convolvuli</i>	35	10	29
Honeysuckle aphid, <i>Rhopalosiphum conii</i>	50	1	2

See footnote 5, page 392.

TABLE 2
TRANSMISSION OF VIRUS BY SINGLE APHIDS THAT BREED ON
CAULIFLOWER UNDER NATURAL CONDITIONS

Species of aphids	Results with wingless mature aphids			Results with winged aphids		
	Cauliflower			Cauliflower		
	Inoculated	Infected	Per cent infected	Inoculated	Infected	Per cent infected
Cabbage aphid, <i>Brevicoryne brassicae</i>	150	28	15	100	22	22
Turnip aphid, <i>Rhopalosiphum pseudobrassicae</i> ...	200	8	4	100	5	5
Green peach aphid, <i>Myzus persicae</i>	100	11	11	150	4	3

From Naturally Infected Cauliflower and Brussels Sprouts. Whenever high populations of the cabbage aphid were found on mosaic-infected cauliflower plants, lots of 20 aphids were transferred to healthy cauliflower and annual stock plants. Table 3 shows the counties and districts from which the source of virus was obtained. The cabbage aphid transmitted the virus to 67 per cent of the cauliflower and to 43 per cent of the annual stock plants. Virus from the Richmond and Colma districts was transmitted to cauliflower but not to stock.

The virus was also transmitted by the cabbage aphid from naturally infected brussels sprouts obtained at El Granda to healthy cauliflower seedlings.

From Experimentally Infected Cauliflower to Healthy Cauliflower and Stock Plants. Lots of 20 cabbage, turnip, and green peach aphids were used in determining the transmission of the virus from mosaic-infected cauliflower to healthy cauliflower seedlings and annual stock plants. Table 4 shows the number and percentages of cauliflower and annual stock plants infected with the virus by means of three species of aphids.

TABLE 3
TRANSMISSION OF CAULIFLOWER-MOSAIC VIRUS FROM NATURALLY
INFECTED TO HEALTHY CAULIFLOWER AND STOCKS BY LOTS OF
20 CABBAGE APHIDS, *BREVICORYNE BRASSICAE*

County and district	Cauliflower		Stocks	
	Inoculated	Infected	Inoculated	Infected
Alameda county:				
Alameda.....	6	3	6	2
Contra Costa County:				
Richmond.....	6	2	6	0
San Pablo.....	6	6	6	4
San Francisco County:				
San Francisco.....	6	3	6	4
San Mateo County:				
Colma.....	6	6	6	4
El Granada.....	6	4	6	0
Monterey County:				
Salinas.....	6	4	6	4
Total.....	42	28	42	18
Percentage.....	.....	67	.....	43

Annual stock plants infected with the virus by the three species of aphids did not show breaking in the color of the petals, as previously reported (Tompkins, 1937). Breaking in the flowers of annual stock is caused by two other viruses (Tompkins, 1934*b*, 1939*a*).

SUSCEPTIBILITY OF VARIETIES OF CAULIFLOWER

Plants of twenty-one varieties of cauliflower were inoculated with the virus to ascertain whether any variety was resistant to the disease. Lots of 20 infective cabbage aphids and green peach aphids were transferred from diseased to healthy cauliflowers, one lot to a plant. Table 5 shows that 78 per cent of the cauliflower seedlings were infected by means of the cabbage aphid and 58 per cent by the green peach aphid. Again, the cabbage aphid was a more efficient vector of the virus than the green peach aphid. All varieties of cauliflower were highly susceptible to cauliflower mosaic.

COMPARATIVE EFFICIENCY OF MECHANICAL INOCULATION AND APHID TRANSMISSION OF VIRUS

The transmission of virus from experimentally infected to healthy cauliflower plants by mechanical inoculation was compared with transmissions by three species of aphids. A summary of virus transmission by aphids (single

TABLE 4
TRANSMISSION OF CAULIFLOWER-MOSAIC VIRUS FROM INFECTED
CAULIFLOWER TO HEALTHY CAULIFLOWER SEEDLINGS AND
ANNUAL STOCKS BY THREE APHID SPECIES

Aphid species and test no.	Cauliflower		Stocks	
	Inoculated	Infected	Inoculated	Infected
<i>Cabbage aphid, Brevicoryne brassicae:</i>				
Test 1.....	10	0	10	9
Test 2.....	5	5	5	5
Test 3.....	5	5	5	3
Test 4.....	5	5	5	3
Test 5.....	5	4	5	5
Test 6.....	5	3	5	2
Test 7.....	5	3	5	0
Total.....	40	25	40	27
Percentage.....	.....	63	.....	69
<i>Turnip aphid, Rhopalosiphum pseudobrassicae:</i>				
Test 1.....	5	3	5	3
Test 2.....	5	3	5	3
Test 3.....	5	3	5	3
Test 4.....	5	3	5	1
Test 5.....	5	2	5	3
Test 6.....	5	0	5	3
Total.....	30	14	30	16
Percentage.....	.....	47	.....	53
<i>Green peach aphid, Myzus persicae:</i>				
Test 1.....	10	10	10	9
Test 2.....	5	5	5	5
Test 3.....	5	5	5	2
Test 4.....	5	4	5	5
Test 5.....	5	4	5	3
Test 6.....	5	3	5	3
Test 7.....	5	2	5	1
Test 8.....	5	3	5	0
Total.....	45	36	45	28
Percentage.....	.....	80	.....	62

and multiple lots) was taken from tables 3, 4, 5 (February cauliflower), and 7. The virus was maintained by repeated mechanical inoculation and aphid transmission. The virus from the same infected plants upon which the aphids had fed was mechanically inoculated into healthy plants. A comparison of the results obtained is given in table 6. It is evident that the three species of aphids were less efficient than mechanical inoculation in transmitting the virus: 89 to 90 per cent of the healthy cauliflower plants became infected when mechanically inoculated; 43 to 67 per cent when the virus was transmitted by aphids.

TABLE 5

TRANSMISSION OF CAULIFLOWER-MOSAIC VIRUS TO VARIETIES OF
CAULIFLOWER BY CABBAGE APHID (*BREVICORYNE BRASSICAE*)
AND GREEN PEACH APHID (*MYZUS PERSICAE*)

Variety of cauliflower	Cabbage aphid		Green peach aphid	
	Plants inoculated	Plants infected	Plants inoculated	Plants infected
April.....	10	9	10	8
February.....	10	10	10	6
Danish Perfection.....	10	10	10	5
December.....	10	7	10	9
Dryweather Danish.....	10	8	20	9
Early March.....	10	6	10	1
Early Snowball.....	10	3	10	7
Extra Early Dwarf Erfurt.....	10	6	10	5
Hartmans Special Early.....	10	10	10	9
Hartmans Special Median.....	10	9	20	8
January.....	10	10	10	7
Late March.....	10	3	10	2
Late Pearl.....	10	6	10	9
November.....	10	10	10	8
St. Valentine.....	10	7	10	9
Super Snowball.....	10	9	10	4
February 759*.....	10	10	10	5
Christmas 2022*.....	20	16	20	8
Early March 713*.....	10	8	10	3
Early March 767*.....	10	9	10	7
Mission Special*.....	10	5	10	9
Total.....	220	171	240	138
Percentage.....	.....	78	.....	58

* The cauliflowers were grown from seeds from Ferry-Morse Seed Co., San Francisco.

TABLE 6

COMPARISON OF TRANSMISSION OF CAULIFLOWER-MOSAIC VIRUS BY
MECHANICAL INOCULATION WITH THREE SPECIES OF APHIDS

Number of plants from which virus was recovered	Mechanical inoculation			Aphids	Aphid transmission		
	Plants inoculated	Plants infected	Per cent infected		Plants inoculated	Plants infected	Per cent infected
27	125	112	90	Cabbage aphid, <i>Brevicoryne brassicae</i>	165	110	67
12	70	63	90	Turnip aphid, <i>Rhopalosiphum pseudobrassicae</i>	70	30	43
20	120	107	89	Green peach aphid, <i>Myzus persicae</i>	120	69	58

RETENTION OF VIRUS

By Varying Numbers of Aphids with Daily Transfers. The retention of the virus was determined with three species of aphids reared on mosaic-infected cauliflower plants. In most tests, lots of 20 aphids were used; but occasionally 10, 5, and single aphids were employed. Each lot of aphids was transferred daily, usually for three days, to successive healthy cauliflower seedlings. In preliminary work the aphids sometimes were transferred daily

TABLE 7
RETENTION OF CAULIFLOWER-MOSAIC VIRUS BY THREE
SPECIES OF APHIDS

Aphid species and number of insects per lot	Number of lots	First day		Second day		Third day	
		Seedlings inoculated	Seedlings infected	Seedlings inoculated	Seedlings infected	Seedlings inoculated	Seedlings infected
Cabbage aphid, <i>Brevicoryne brassicae</i> :							
1 per lot.....	3	18	4	18	0	18	0
5 per lot.....	1	6	2	6	0	6	0
10 per lot.....	1	7	7	7	0	7	0
20 per lot.....	7	42	34	42	0	42	0
Turnip aphid, <i>Rhopalosiphum pseudobrassicae</i> :							
20 per lot.....	6	40	16	40	0	40	0
Green peach aphid, <i>Myzus persicae</i> :							
5 per lot.....	2	10	2	10	0	10	0
20 per lot.....	9	55	29	55	0	55	0

for 30 days to successive healthy cauliflower seedlings. These preliminary tests are not tabulated, but no transmissions were obtained after the first day.

As shown in table 7, each of the three species of aphids transmitted the virus from diseased to healthy cauliflower during the first day; but none of the lots tested produced infection during the second or third day.

By Lots of 20 Aphids with Hourly Transfers. An attempt was made to determine more precisely how long the cabbage, turnip, and green peach aphids retained the cauliflower-mosaic virus. Each of 3 lots of 20 wingless, mature aphids of each species, reared on mosaic-infected cauliflower plants, was transferred hourly to 10 successive healthy plants.

As table 8 shows, 2 of 3 lots of 20 cabbage aphids transmitted the virus during the first and second hours and 1 lot during the first hour only. Each lot of the other two species of aphids transmitted the virus during the first hour only.

By Single Aphids in Short Feeding Time. Previously noninfective, mature, wingless aphids were starved for a period of 30 minutes in a stentor dish, with the bottom covered with moist filter paper. Each aphid was transferred with a moistened camel's-hair brush from the moist chamber to a mosaic-infected

cauliflower plant and allowed to feed for 5 or 10 minutes. Some of the aphids crawled about on the leaf, but after finding a suitable feeding place they settled down, with the antennae parallel to the body and the labium at right angles to the leaf and touching it. Each aphid was observed through a hand lens, and when it did not immediately withdraw the stylets, the feeding time was taken.

TABLE 8
RETENTION OF CAULIFLOWER-MOSAIC VIRUS BY THREE SPECIES OF
APHIDS TRANSFERRED HOURLY TO 10 SUCCESSIVE
HEALTHY CAULIFLOWER SEEDLINGS

Aphid species and lot no.	Number of aphids on first plant	Results on successive plants, with hourly transfers*										Last infection produced by aphids, hour
		1st	2d	3d	4th	5th	6th	7th	8th	9th	10th	
Cabbage aphid, <i>Brevicoryne brassicae</i> :												
Lot 1.....	20	+	+	-	-	-	-	-	-	-	-	2d
Lot 2.....	20	+	+	-	-	-	-	-	-	-	-	2d
Lot 3.....	20	+	-	-	-	-	-	-	-	-	-	1st
Turnip aphid, <i>Rhopalosiphum pseudobrassicae</i> :												
Lot 1.....	20	+	-	-	-	-	-	-	-	-	-	1st
Lot 2.....	20	+	-	-	-	-	-	-	-	-	-	1st
Lot 3.....	20	+	-	-	-	-	-	-	-	-	-	1st
Green peach aphid, <i>Myzus persicae</i> :												
Lot 1.....	20	+	-	-	-	-	-	-	-	-	-	1st
Lot 2.....	20	+	-	-	-	-	-	-	-	-	-	1st
Lot 3.....	20	+	-	-	-	-	-	-	-	-	-	1st
Total +.....	..	9	2	0	0	0	0	0	0	0	0	....
Total -.....	..	0	7	9	9	9	9	9	9	9	9	....

* The plus sign (+) indicates the production of the disease, and the minus (-) shows that no disease resulted.

The time occupied by each aphid in finding a suitable feeding place and settling down to feed, is referred to by Watson (1936) as the "penetration time," but probably should be designated as prepenetration time. The average prepenetration time was 5.1 minutes with the cabbage aphid, 3.6 minutes with the turnip aphid, and 4.7 minutes with the green peach aphid (table 9).

After feeding 5 or 10 minutes on a mosaic-infected cauliflower plant, each aphid was transferred to a healthy cauliflower seedling; and it was fed for 5 or 10 minutes. The aphid then was transferred to 5 more healthy cauliflower seedlings in succession and fed 10 minutes on each.

Three species of aphids were tested in this way. Table 9 shows the results with those aphids that transmitted the virus to at least one healthy cauliflower seedling. As this table shows, 25 cabbage aphids, 5 turnip aphids, and 5 green peach aphids, each tested singly, produced infections only in the first cauliflower seedling. One cabbage aphid after feeding 5 minutes on a diseased cauliflower seedling failed to infect the first two healthy cauliflower seedlings, but infected the third plant. One green peach aphid caused an infection of

TABLE 9
RETENTION OF CAULIFLOWER-MOSAIC VIRUS BY SINGLE APHIDS
TRANSFERRED AT 5- OR 10-MINUTE INTERVALS TO SIX
SUCCESSIVE HEALTHY CAULIFLOWER SEEDLINGS

Aphid species and insect no.	Time on diseased cauliflower, minutes		Results* on successive plants, with 10 minutes† per plant					
	Prepen- etration time	Feeding time	1st plant†	2nd plant	3rd plant	4th plant	5th plant	6th plant
Cabbage aphid, <i>Brevicoryne brassicae</i>:								
No. 1.....	10	5	—	—	+	—	—	—
No. 2.....	13	10	+	—	—	—	—	—
No. 3.....	11	10	+	—	—	—	—	—
No. 4.....	11	10	+	—	—	—	—	—
No. 5.....	11	10	+	—	—	—	—	—
No. 6.....	7	10	+	—	—	—	—	—
No. 7.....	7	10	+	—	—	—	—	—
No. 8.....	7	10	+	—	—	—	—	—
No. 9.....	6	10	+	—	—	—	—	—
No. 10.....	6	10	+	—	—	—	—	—
No. 11.....	6	10	+	—	—	—	—	—
No. 12.....	5	10	+	—	—	—	—	—
No. 13.....	5	10	+	—	—	—	—	—
No. 14.....	5	10	+	—	—	—	—	—
No. 15.....	5	10	+	—	—	—	—	—
No. 16.....	5	10	+	—	—	—	—	—
No. 17.....	5	10	+	—	—	—	—	—
No. 18.....	4	10	+	—	—	—	—	—
No. 19.....	4	10	+	—	—	—	—	—
No. 20.....	4	10	+	—	—	—	—	—
No. 21.....	4	10	+	—	—	—	—	—
No. 22.....	4	10	+	—	—	—	—	—
No. 23.....	3	10	+	—	—	—	—	—
No. 24.....	2	10	+	—	—	—	—	—
No. 25.....	2	10	+	—	—	—	—	—
No. 26.....	1	10	+	—	—	—	—	—
Total or average.....	5.1	..	25+, 1—	26—	1+, 25—	26—	26—	26—
Turnip aphid, <i>Rhopalosiphum pseudobrassicae</i>:								
No. 1.....	7	10	+	—	—	—	—	—
No. 2.....	4	10	+	—	—	—	—	—
No. 3.....	3	10	+	—	—	—	—	—
No. 4.....	2	10	+	—	—	—	—	—
No. 5.....	2	10	+	—	—	—	—	—
Total or average.....	3.6	..	5+	5—	5—	5—	5—	5—
Green peach aphid, <i>Myzus persicae</i>:								
No. 1.....	7	5	+	—	+	—	—	—
No. 2.....	6	5	+	—	—	—	—	—
No. 3.....	6	5	+	—	—	—	—	—
No. 4.....	5	5	+	—	—	—	—	—
No. 5.....	3	5	+	—	—	—	—	—
No. 6.....	2	5	+	—	—	—	—	—
Total or average.....	4.7	..	6+	6—	1+, 5—	6—	6—	6—

* The plus sign (+) indicates the production of the disease, and the minus (—) shows that no disease resulted.

† The feeding time on the first plant was 5 minutes for cabbage aphid no. 1 and all green peach aphids; all other feeding periods on healthy plants were 10 minutes.

the first cauliflower plant, failed to infect the second, but infected the third. Negative results are not shown in table 9: 72 cabbage, 41 turnip, and 40 green peach aphids tested singly in short feeding periods failed to transmit the virus.

TABLE 10
LOSS AND RECOVERY OF INFECTIVITY BY APHIDS ON CAULIFLOWER
PLANTS INOCULATED WITH CAULIFLOWER-MOSAIC VIRUS

Aphid species and first inoculated plant no.	Results* when a lot of 20 aphids was transferred from the first inoculated plant to a second healthy plant on the following day											Days to first symptom on first inoculated plant
	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	
Cabbage aphid, <i>Brevicoryne brassicae</i> :												
Plant 1.....	—	—	+	+	+	+	+	+	+	+	—	18
Plant 2.....	—	—	—	—	—	+	—	+	+	—	—	20
Plant 3.....	—	—	—	—	—	—	—	+	—	—	+	21
Plant 4.....	—	—	—	—	—	+	+	+	—	—	+	24
Plant 5.....	—	—	—	—	—	—	+	+	+	+	+	25
Plant 6.....	—	—	—	—	—	—	+	—	—	—	—	30
Total +.....	0	0	1	1	1	3	4	5	3	2	3	
Total —.....	6	6	5	5	5	3	2	1	3	4	3	
Green peach aphid, <i>Myzus persicae</i> :												
Plant 7.....	—	—	—	+	—	—	—	—	—	—	+	30
Plant 8.....	—	—	—	—	—	—	—	—	—	—	+	33
Total +.....	0	0	0	1	0	0	0	0	0	0	2	
Total —.....	2	2	2	1	2	2	2	2	2	2	0	

The plus sign (+) indicates the production of the disease, and the minus (-) shows that no disease resulted.

RECOVERY OF VIRUS BY APHIDS FROM AN INOCULATED
PLANT BEFORE SYMPTOMS DEVELOP

An attempt was made to determine whether the cabbage and green peach aphids were able to recover the virus from inoculated cauliflower plants before the first symptom of the disease developed. A large population of aphids reared on mosaic-infected cauliflower plants was transferred to a healthy cauliflower plant for 3 days. Each day from the fourth to the fourteenth day, one lot of 20 of these aphids was transferred from the plant so inoculated to a healthy cauliflower plant. Each lot of aphids remained on the second inoculated plant for 3 days and then the plant was fumigated to kill the aphids. The results reported in table 7 indicate that the aphids do not retain the virus longer than 1 day. Therefore the aphids were presumed to have lost their infectivity before transfer to the second healthy plant; and any transmission that occurred may be attributed to recovery of the virus from the first inoculated plant.

The transmissions by the two aphid species and also the incubation period of the disease, or the period for the earliest symptom (cleared veinlets) to develop in the original infected cauliflower plant, are shown in table 10. With the cabbage aphid, the elapsed time to the first recovery of the virus varied from 6 to 11 days. The incubation period of the disease in the original infected

cauliflower plants varied from 18 to 30 days. With the green peach aphid, the elapsed time to the first recovery of the virus was 7 days with one lot, 14 days with the other. The incubation periods of the disease in the original infected cauliflower plants were 30 and 33 days, respectively. Fourteen additional lots of aphids, not tabulated in table 10, failed to recover the virus from the fourth to fourteenth day.

The fact that no transmissions occurred on the fourth or fifth day supports the assumption that the aphids had lost the infectivity acquired on the original mosaic-infected plant before they were transferred to the second healthy plant. The results show that the aphids were able to recover the virus from the first inoculated plant before symptoms developed on it.

MECHANICAL INOCULATION WITH VIRUS EXTRACT FROM CRUSHED APHIDS

An attempt was made to transmit the cauliflower-mosaic virus with the centrifuged virus extract of crushed, infective cabbage aphids by mechanical inoculation of healthy cauliflower and annual stock plants. The centrifuged virus extract prepared from 10 grams of infective cabbage aphids crushed in 90 cc of sterile distilled water was inoculated in 10 healthy cauliflower seedlings and 10 annual stock plants. Four cauliflower and 8 annual stock plants were infected. In three other tests, 4.3, 4.0 and 0.68 grams of infective cabbage aphids were crushed in sterile distilled water. The results obtained with the virus extract inoculated into healthy cauliflower seedlings and annual stock plants were as follows: 4.3 grams, 20 plants inoculated remained healthy; 4.0 grams, 1 of 10 annual stock plants became infected, 10 cauliflower plants inoculated remained healthy; and 0.68 grams, 1 of 10 cauliflower seedlings became infected, 10 annual stock plants remained healthy. Of a total of 80 plants inoculated, 14, or 18 per cent, became infected.

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Plate 1. Symptoms of cauliflower mosaic on leaves of cauliflower (*Brassica oleraceae* var. *botrytis*): A, leaf from healthy check or control plant; B, vein clearing; C, veinbanding, mottling, and distortion; D, curvature of the midrib; E, F, necrotic lesions; G, necrotic spotting, curvature of the midrib, and distortion.

Plate 2. Symptoms of cauliflower mosaic on stock plants (*Matthiola incana* var. *annua*): A, plant infected by means of green peach aphid (*Myzus persicae*) showing shortened internodes and secondary shoots; B, leaf from healthy check or control plant; C, clearing of veins; D, leaf from plant infected with cabbage aphid (*Brevicoryne brassicae*) showing circular chlorotic areas; E, mottling; F, protruding veins on lower surface of leaf.

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