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Transmission of Carrot, Parsley, and Parsnip Yellows by Cicadula Divisa

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TRANSMISSION OF CARROT, PARSLEY, AND PARSNIP YELLOWS BY CICADULA DIVISA[1]

HENRY H. P. SEVERIN[2]

(Contribution from the Division of Entomology and Parasitology, California Agricultural Experiment Station, University of California, cooperating with the United States Department of Agriculture, Bureau of Entomology.)

INTRODUCTION

A number of plant pathologists have called attention to a disease of carrots having most of the characteristic symptoms of yellows, but whether it was caused by the aster-yellows virus remained to be determined.

In New York, Whetzel[8] reported a yellows disease of carrots ranging from a trace to 25 per cent infection in the Williamson area. Folsom[1] found apparently the same carrot disease as described by Whetzel, at Orono, Maine, and on the experimental farm in the southwestern part of the state. Zundel[9] reported observations of yellows believed to be caused by the aster-yellows virus in carrots in Cumberland County, Pennsylvania. Vaughan and Foster[7] found a disease of carrots in Wisconsin resembling aster yellows and assumed that it may be due to the same virus. The diseased carrots were growing adjacent to an experimental aster-yellows plot. Newhall[3] reported a disease of carrots thought to be due to the aster-yellows virus in Wayne and Oswego counties, New York.

Severin[6] published a summary of the transmission of yellows from naturally and experimentally infected carrots and parsley to asters and

[1] Received for publication May 25, 1932.

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celery, and from the infected asters and celery back to carrots and parsley. Kunkel,[2] however, questions whether carrot yellows of California is identical with aster yellows of the East, since carrot yellows is readily transmitted to celery (*Apium graveolens* var. *dulce*) and to *Zinnia elegans,* plants that are highly resistant if not immune to aster yellows.

During the spring and late summer of 1929 a survey was made of the yellows disease of plants grown on the ranch of the Morse Seed Company located in the Salinas Valley, California. It was observed during early June that the inner leaves of many varieties of carrots were yellow, but the plants were small and the symptoms were just beginning to develop. During the late summer the white varieties of carrots and parsley showed some of the characteristic symptoms of yellows but, unfortunately, the orange varieties of carrots had been pulled.

During the summer of 1931 another trip was taken to the ranch of the Morse Seed Company and both white and orange varieties of carrots showed typical symptoms of yellows. Parsnips also showed symptoms of yellows. Carrot yellows was also found in the truck-crop gardens between Davis and Sacramento.

An investigation was undertaken to determine whether the disease of carrots, parsley, and parsnips was caused by the virus of aster and celery yellows. Successive inoculations were attempted from asters and celery naturally and experimentally infected with yellows to healthy carrots, parsley, and parsnips by means of *Cicadula divisa* Uhl. The transfer of yellows from experimentally infected carrots, parsley, and parsnips back to healthy asters and celery was attempted with previously non-infective leafhoppers. Cross inoculations were tested from infected carrots to healthy ones, from parsley to parsley, carrots to parsley, and parsley to carrots. The longevity of the leafhopper and the life cycle on carrots, parsley, and parsnips was also determined.

In this investigation, the virus of carrot yellows has been compared only with that of the aster yellows present in this state; the question of whether the carrot-yellows virus is identical with the aster yellows of the eastern and middle western states is under investigation at present.

CARROT YELLOWS

Symptoms.—Carrot (*Daucus carota* var. *sativa*) plants naturally infected with yellows showed a marked yellowing of the younger central leaves, while the older outer leaves were usually reddened or purple. The discoloration of the older outer leaves often failed to develop in carrots experimentally infected with the disease in the greenhouse. The

younger central leaves were dwarfed and the petioles sometimes twisted (figs. 1, 2); occasionally a dense growth of adventitious chlorotic shoots developed at the center of the crown (figs. 3, 4). The leaflets on the

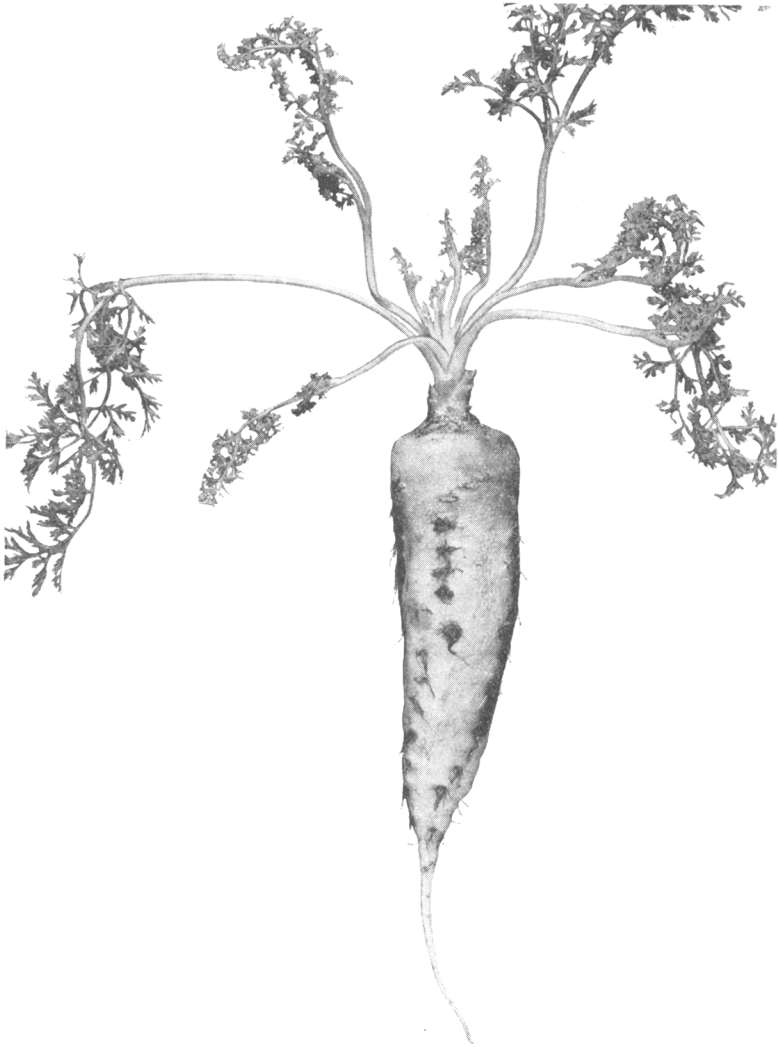

Fig. 1. White Belgian carrot naturally infected with yellows, showing dwarfed central leaves with some of the petioles twisted.

shortened petioles were sometimes reduced to short filaments, which often became dry. Carrot plants experimentally infected with yellows sometimes developed a short central seed stalk or several seed stalks,

and a constriction sometimes occurred below the crown of the carrot. Carrots in an advanced stage of the disease showed numerous bunched rootlets arising from elevations on the carrot root (figs. 1, 3).

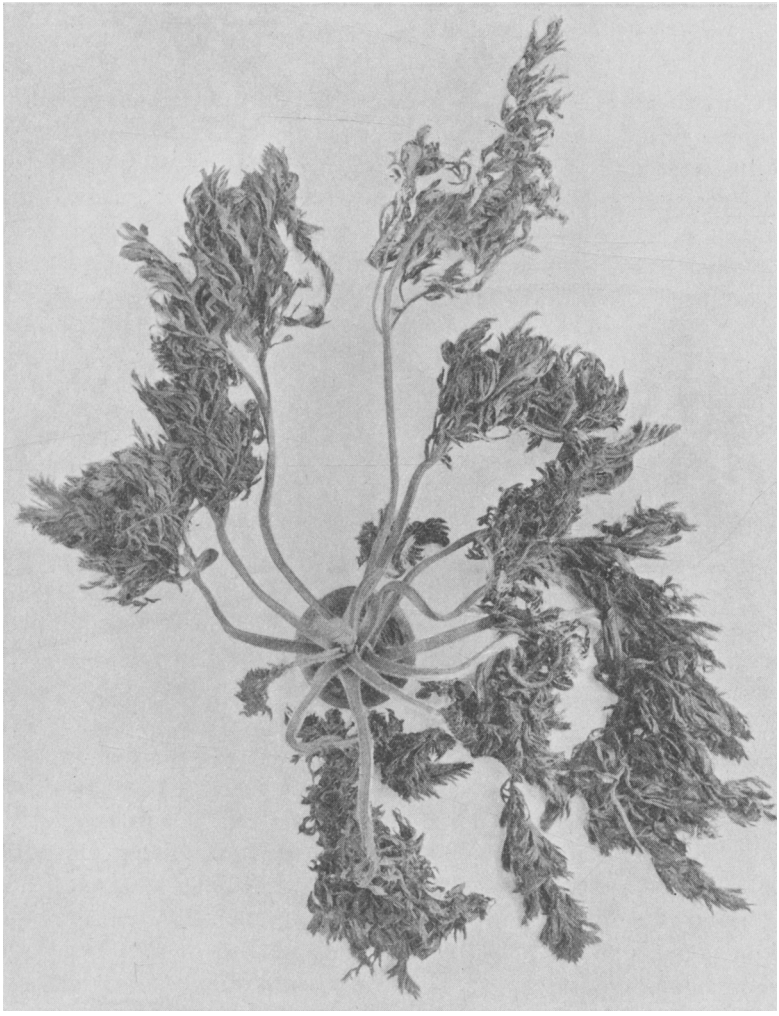

Fig. 2. Short White carrot naturally infected with yellows, showing twisted petioles in a top view.

Incubation Period.—The incubation period of the disease was determined in 3 white, 1 yellow, and 7 orange varieties of carrots. The length of time that elapses from the inoculation of the plant by infective leafhoppers until the youngest leaves became chlorotic or the

petioles began to twist was considered as the incubation period of the disease. Carrots used as a check or control remained healthy.

In two experiments small and large carrots were experimentally infected with yellows by the leafhoppers reared on naturally infected celery. The minimum, maximum, mean, and average incubation periods in varieties of carrots are given in table 1.

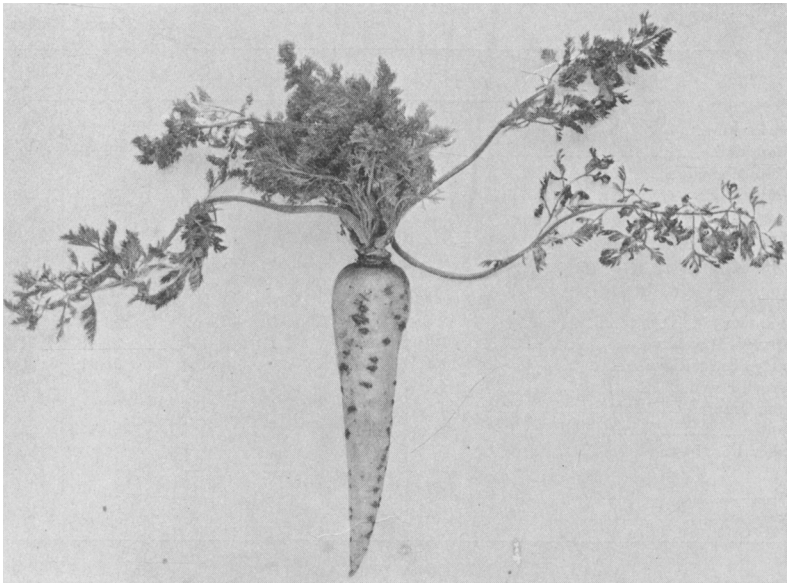

Fig. 3. White Belgian carrot naturally infected with yellows, showing dense growth of adventitious shoots at the center of the crown.

A comparison of the averages in table 1 shows that the incubation period is shorter in small (young) carrots than in large ones. In all probability large carrots are more resistant to the disease. Similar results were obtained with curly top of sugar beets[4]—the smaller the beet the shorter the incubation period of the disease.

The incubation period of the disease in carrots infected by previously noninfective leafhoppers which had fed on naturally infected asters is shown in table 2. The minimum incubation period varied from 15 to 29 days with an average of 22.7 days. The maximum incubation period ranged from 34 to 76 days with an average of 46.5 days. The average percentage of infection of the white varieties of carrots was 65.2, of the yellow 18.7, and of the orange 51.1. The Yellow Belgian carrot was most resistant to the disease.

TABLE 1

INCUBATION PERIOD OF YELLOWS DISEASE IN CARROTS INFECTED BY CICADULA DIVISA BRED ON NATURALLY INFECTED CELERY

Variety	Plants inoculated	Leafhoppers on each plant	Plants infected	Plants healthy	Incubation period in plant, days	
					Range	Mean
Small (young) carrots						
White varieties:						
Short White	5	25	2	3	19–20	19.5
White Mastodon	4	25	1	3	103	.....*
White Belgian	2	25	2	0	18–22	20.0
Yellow varieties:						
Yellow Belgian	2	25	0	2	.....	.....
Orange varieties:						
Chantenay	2	25	2	0	20–21	20.5
Danvers Half Long	4	25	4	0	21–41	31.0
Early Scarlet Horn	2	25	2	0	21–31	26.0
French Forcing	4	25	2	2	19–22	20.5
Long Orange	2	25	1	1	25	.....*
Nantes	2	25	0	2	.....	.....
Oxheart or Guerande	2	25	1	1	48	.....*
Total	31	....	17	14	.....	.....
Average	....	25	....	....	.....	22.9
Large carrots						
White varieties:						
Short White	2	25	1	1	21	.....*
White Mastodon	2	25	0	2	.....	.....
White Belgian	2	25	1	1	23	.....*
Yellow varieties:						
Yellow Belgian	6	25	1	5	21	.....*
Orange varieties:						
Chantenay	6	25	2	4	26–35	30.5
Danvers Half Long	2	25	0	2	.....	.....
Early Scarlet Horn	6	25	3	3	28–56	42.0
French Forcing	2	25	0	2	.....	.....
Long Orange	2	25	1	1	47	.....*
Nantes	3	25	0	3	.....	.....
Oxheart or Guerande	6	25	2	4	26–88	57.0
Total	39	....	11	28	.....	.....
Average	....	25	....	....	.....	43.2

* No mean given because only one plant became infected.

Recovery of Virus.—The transmission of yellows by previously noninfective leafhoppers from orange varieties of carrots naturally infected with the disease to healthy asters and celery is shown in table 3. Five lots of 20 noninfective leafhoppers each were exposed for a period of 2 days on 5 carrot-yellows plants, one lot to a plant, and then 10

Fig. 4. Short White carrot naturally infected with yellows, showing central adventitious shoots with outer leaves removed.

insects of each lot were exposed for 20 days to a healthy aster, and 10 insects of each lot to a healthy celery plant. Each lot was then transferred to another healthy aster or another healthy celery plant and kept on these plants for a period of 7 days. A third set of celery plants were exposed for a period of 7 days to the leafhoppers which had previously been fed on the second set of celery plants, except one lot of insects, which had died.

TABLE 2

INCUBATION PERIOD OF YELLOWS DISEASE IN CARROTS INFECTED BY PREVIOUSLY NONINFECTIVE CICADULA DIVISA FED ON NATURALLY INFECTED ASTERS

Variety	Plants inoculated	Leafhoppers on each plant	Plants infected	Plants healthy	Incubation period in plant		
					Minimum	Maximum	Mean
White varieties:					*days*	*days*	*days*
Short White	7	25	5	2	21	45	32.4
White Mastodon	8	25	4	4	25	42	36.7
White Belgian	8	25	6	2	23	76	43.2
Yellow varieties:							
Yellow Belgian	16	25	3	13	26	40	34.7
Orange varieties:							
Chantenay	4	25	3	1	29	36	29.3
Danvers Half Long	7	25	3	4	23	37	29.7
Early Scarlet Horn	5	25	4	1	22	49	35.5
French Forcing	7	25	4	3	25	40	33.3
Long Orange	9	25	3	6	20	34	26.7
Nantes	8	25	2	6	15	72	43.5
Oxheart or Guerande	5	25	4	1	21	41	30.7
Total	84	....	41	43	....	....	.....
Average	....	25	....	....	22.7	46.5	34.2

TABLE 3

TRANSMISSION OF YELLOWS BY PREVIOUSLY NONINFECTIVE CICADULA DIVISA FROM CARROTS NATURALLY INFECTED WITH THE DISEASE TO HEALTHY ASTERS AND CELERY*

Carrot plant No.	Results with asters		Results with celery		
	First set	Second set	First set	Second set	Third set
1	+	+	+	+	+
2	−	−	+	+	....†
3	+	−	−	−	−
4	+	+	+	+	+
5	+	−	+	+	+
Total positive (+)	4	2	4	4	3
Total negative (−)	1	3	1	1	1

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

† Insects died.

It is evident from table 3 that 10 leafhoppers which fed on carrot plant No. 2, failed to transmit yellows to either of the asters, while 10 insects which fed on the same diseased carrot transmitted yellows to 2 successive celery plants. The third plant was not tried with this lot of leafhoppers because the insects died. In the case of carrot plant No. 3,

yellows was transmitted to the first aster but not to the second. Another group of 10 leafhoppers which fed on the same diseased carrot failed to transmit yellows to 3 successive celery plants.

In similar tests, previously noninfective leafhoppers, after feeding on Short White and White Belgian carrot plants naturally infected with yellows, transmitted the disease to asters, Erfurt Giant celeriac (*Apium graveolens* var. *rapaceum*), and the following varieties of celery: Golden Self-Blanching, Large Smooth Prague, and Rosy Plume (*Apium graveolens* var. *dulce*).

Successive inoculations were made from each variety of carrot experimentally infected with the disease to celery or asters or both and back to carrots. Previously noninfective leafhoppers after feeding on carrot plants infected with yellows often transmitted the disease to celery and asters but numerous trials were required to transfer the disease from infected celery or asters back to carrots. Repeated lots of leafhoppers were often used in the transfer of yellows from infected celery or asters back to carrots. Better results were obtained in the transmission of the disease when small carrot plants were used. The disease was not transmitted from inoculated carrots which failed to show symptoms of the disease.

The transmission of the disease from carrots experimentally infected with yellows to the same variety of carrot also required numerous trials. The leafhoppers on healthy carrots often died before the incubation period of the virus was completed in the insects. It was found, however, that the males lived longer on diseased than on healthy carrots, and hence the insects were kept on diseased carrots for a period of 2 to 3 weeks so that the incubation period was completed before transferring them to healthy carrots. Females lived longer than males on carrots, and hence females were allowed to deposit their eggs in the petioles of diseased carrots, and after the nymphs hatched and fed for a period of about three weeks they were transferred to healthy carrots.

Inoculations of Healthy Celery by Means of Leafhoppers Fed on Filtered Juice from Carrots Infected with Yellows.—All attempts to transmit yellows by feeding noninfective *Cicadula divisa* on the filtrate prepared from carrots infected with yellows and then transferring the insects to healthy celery were failures. The juice was extracted from a total of 15 Short White and White Belgian carrots naturally infected with yellows and filtered through coarse and fine Berkefeld candles. The leafhoppers after feeding on the filtrate for a period of 3 hours were transferred to 56 healthy celery plants but without effect. The filtrate was a favorable food for the leafhoppers.

Longevity and Life Cycle of Cicadula Divisa on Carrots.—The longevity of the last living male on each variety of carrot during the spring, summer, and autumn is shown in table 4. Most of the males died a few days after being exposed to healthy varieties of carrots. The mortality was higher on small carrots than on large ones. After the plants developed symptoms of yellows the insects lived longer. It is possible that the virus produces changes in the sap of the carrot which are of some biological significance to the insect, as was suggested in a previous paper.[5] The leafhopper completed its life cycle on all varieties of carrots infected with yellows except Yellow Belgian. A low population acquired the adult stage on most varieties of carrots.

TABLE 4

LONGEVITY OF LAST LIVING MALE CICADULA DIVISA ON VARIETIES OF CARROTS

Variety	Longevity of males		
	Minimum	Maximum	Average
White varieties:	*days*	*days*	*days*
Short White	5	14	9.0
White Mastodon	2	30	10.5
White Belgian	4	16	7.7
Yellow varieties:			
Yellow Belgian	3	26	9.5
Orange varieties:			
Chantenay	2	25	7.7
Danvers Half Long	2	10	5.2
Early Scarlet Horn	4	28	15.4
French Forcing	8	26	14.2
Long Orange	7	30	12.5
Nantes	4	31	13.0
Oxheart or Guerande	2	31	9.6

YELLOWS OF HAMBURG OR TURNIP-ROOTED PARSLEY

Hamburg or Turnip-rooted parsley (*Petroselinum hortense* var. *radicosum*) naturally or experimentally infected with yellows showed a dense growth of chlorotic leaves at the center of the crown (fig. 5). These leaves were dwarfed with upright petioles frequently twisted (fig. 6). The symptoms in experimentally infected varieties of parsley were similar to those observed in the field.

Twelve Hamburg or Turnip-rooted parsley plants were inoculated with from 5 to 25 infective *Cicadula divisa* and six plants developed typical symptoms of yellows. Table 5 shows that the incubation period

of the disease in Hamburg parsley varied from 36 to 106 days, with an average of 65.2 days. The longer incubation periods were obtained with Hamburg parsley infected during the winter.

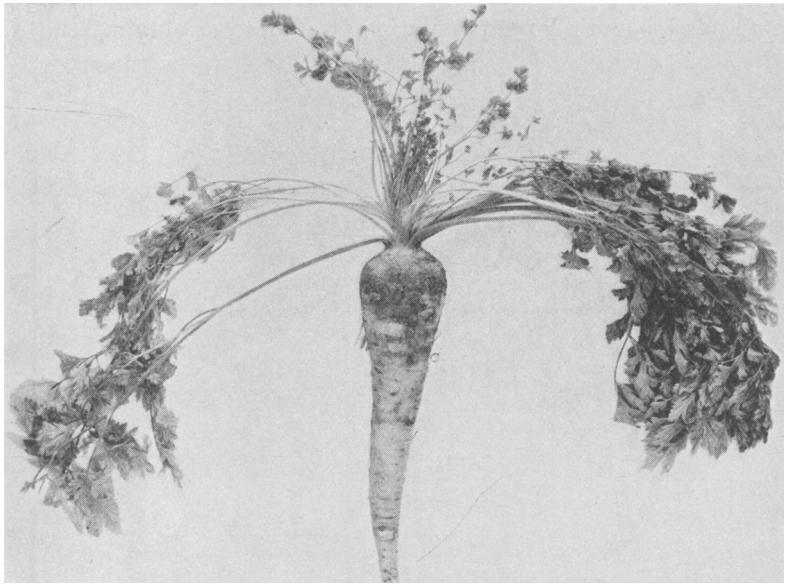

Fig. 5. Hamburg or Turnip-rooted parsley naturally infected with yellows, showing a dense growth of dwarfed leaves at the center of the crown.

TABLE 5

INCUBATION PERIOD OF YELLOWS DISEASE IN HAMBURG OR TURNIP-ROOTED PARSLEY INFECTED BY CIDADULA DIVISA

Plants inoculated	Leaf-hoppers on each plant	Plants infected	Plants healthy	Incubation period in plant
				days
1	15	1	0	36
1	10	1	0	42
1	10	1	0	49
1	10	1	0	56
1	5	1	0	102
1	15	1	0	106
6	25	0	6	.....
Total: 12	....	6	6	.....
Average	....	....	....	65.2

Successive inoculations were made from Hamburg parsley naturally and experimentally infected with yellows to celery or asters and from these plants back to the same variety of parsley. The disease was also

transmitted from infected Hamburg parsley to the same variety of parsley, to Short White, and White Belgian carrots, and from the white varieties of carrots back to Hamburg parsley.

The leafhopper completed its life cycle on Hamburg or Turnip-rooted parsley and a large population of adults was obtained.

Fig. 6. Leaves showing curved petioles from Hamburg or Turnip-rooted parsley naturally infected with yellows.

YELLOWS OF SINGLE OR PLAIN PARSLEY

The symptoms of the disease in Single or Plain parsley (*Petroselinum hortense*) experimentally infected with yellows were somewhat similar to those of Hamburg or Turnip-rooted parsley. The youngest leaves were yellow and the upright petioles were often twisted. Secondary chlorotic shoots sometimes developed.

Thirteen plants were inoculated by from 10 to 25 infected leafhoppers and seven plants developed typical symptoms of yellows. The incubation period of the disease varied from 36 to 58 days with an average of 48.7 days as shown in table 6.

The virus was recovered by previously noninfective leafhoppers from experimentally infected Single or Plain parsley, and yellows was transmitted to healthy celery and asters and from these plants back to the same variety of parsley.

A low population of adult leafhoppers was bred on this variety of parsley after symptoms of yellows developed.

TABLE 6

INCUBATION PERIOD OF YELLOWS DISEASE IN SINGLE OR PLAIN PARSLEY INFECTED BY CICADULA DIVISA

Plants inoculated	Leafhoppers on each plant	Plants infected	Plants healthy	Incubation period in plant
				days
1	25	1	0	36
1	25	1	0	38
1	10	1	0	40
1	15	1	0	56
1	25	1	0	56
1	25	1	0	57
1	20	1	0	58
6	10-25	0	6	....
Total: 13	....	7	6	....
Average	....	....	....	48.7

YELLOWS OF DOUBLE CURLED, EXTRA TRIPLE CURLED, AND FERN LEAF OR MOSS CURLED PARSLEY

These three varieties of parsley (*Petroselinum hortense* var. *crispum*) experimentally infected with yellows showed dwarfed, chlorotic, innermost leaves sometimes with twisted or curled petioles.

The incubation period of the disease in the three varieties of parsley is given in table 7. Twelve Double Curled parsley plants were inoculated but only one plant developed symptoms of yellows. The incubation period of the disease was 37 days. The incubation period of the disease in Triple Curled parsley varied from 32 to 39 days with an average of 37 days, in Fern Leaf or Moss Curled parsley from 39 to 50 days, with an average of 44.6 days.

Cross-inoculations from the three varieties of parsley showing symptoms of yellows to celery and asters were failures.

The longevity of the last living male and female leafhopper on the three varieties of parsley is shown in table 8. The average adult life of

the females was longer than the males. The life cycle was not completed on the three varieties of parsley.

Nymphs which hatched from eggs deposited in the three varieties of parsley failed to complete their life cycle in the greenhouse.

TABLE 7

INCUBATION PERIOD OF YELLOWS DISEASE IN VARIETIES OF PARSLEY INFECTED BY CICADULA DIVISA

Variety	Plants inoculated	Leaf-hoppers on each plant	Plants infected	Plants healthy	Incubation period in plant
					days
Double Curled	1	10	1	0	37
	11	10-60	0	11	
Total	12	....	1	11	....
Extra Triple Curled	1	25	1	0	32
	1	25	1	0	36
	1	10	1	0	39
	1	25	1	0	39
	1	25	1	0	39
	11	10-30	0	11	....
Total	16	....	5	11	.....
Average	....	....	....	....	37.0
Fern Leaf or Moss Curled	1	25	1	0	39
	1	25	1	0	43
	1	25	1	0	43
	1	25	1	0	43
	1	25	1	0	47
	1	25	1	0	47
	1	25	1	0	50
	14	25-45	0	14	....
Total	21	....	7	14	....
Average	....	....	....	....	44.6

TABLE 8

LONGEVITY IN DAYS OF LAST LIVING MALE AND FEMALE CICADULA DIVISA ON THREE VARIETIES OF PARSLEY

Variety	Longevity of males, in days			Longevity of females, in days		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Double Curled	2	29	11.1	14	20	16.3
Extra Triple Curled	3	29	16.0	9	25	17.3
Fern Leaf or Moss Curled	2	33	9.1	11	34	19.0

YELLOWS OF HOLLOW CROWN PARSNIP

Hollow Crown parsnip (*Pastinaca sativa*) naturally infected with yellows showed dwarfed, chlorotic, innermost leaves with twisted petioles (fig. 7). Plants grown from seeds experimentally infected with yellows showed similar symptoms in the greenhouse. The check or control plants remained healthy.

Fig. 7. Hollow Crown parsnip naturally infected with yellows, showing dwarfed leaves and twisted petioles.

The average incubation period of the disease in experimentally infected plants was 40 days.

The virus was recovered by previously noninfective leafhoppers from naturally and experimentally infected parsnip. Yellows was trans-

mitted to healthy celery and asters and from these plants back to healthy parsnips.

Hollow Crown parsnip was a favorable food plant of the leafhopper and the life cycle was completed on this variety of parsnip.

SUMMARY

Experiments demonstrated that previously noninfective *Cicadula divisa* after feeding on Short White, White Belgian, and orange varieties of carrots, Hamburg or Turnip-rooted parsley, and Hollow Crown parsnip naturally infected with yellows, became infective and transmitted typical yellows to healthy asters and celery. Previously noninfective leafhoppers, after feeding on the experimentally infected asters and celery transmitted the disease back to the same varieties of carrots, parsley, and parsnip.

Eleven varieties of carrots, five varieties of parsley, and one variety of parsnip were experimentally infected with yellows by infective leafhoppers. After symptoms of yellows developed, previously noninfective leafhoppers feeding on all of the experimentally infected varieties of carrots, Hamburg or Turnip-rooted and Single or Plain parsleys, and Hollow Crown parsnip transmitted the disease to healthy asters and celery. The disease was transmitted from infected asters and celery back to healthy carrots, Hamburg or Turnip-rooted, and Single or Plain parsleys, and Hollow Crown parsnip. The virus was not recovered from Double Curled, Extra Triple Curled, and Fern Leaf or Moss Curled parsleys. Yellows disease was also transmitted from infected carrots to healthy ones, and similarly from parsley to parsley, carrot to parsley, and parsley to carrot.

These experiments prove that the virus of carrot, parsley, and parsnip yellows can be transmitted to asters and celery. The virus used in the transmission experiments was obtained from carrots, parsley, and parsnips infected with yellows in the field and from asters and celery infected with yellows under natural conditions. The experiments demonstrate that the virus of carrots, parsley, and parsnip yellows is identical with California aster and celery yellows.

The average incubation period of the disease in small carrots was 22.9 days and in large carrots 43.2 days. In all probability large carrots are more resistant to the disease. The minimum incubation period of the disease in carrots varied from 15 to 29 days, and the maximum incubation period ranged from 20 to 103 days. The incubation period of the disease in Hamburg or Turnip-rooted parsley varied from 36 to 106 days, with an average of 65.2 days. The longer incubation periods were

obtained during the winter. The incubation period of the disease in Single or Plain parsley ranged from 36 to 58 days with an average of 48.7 days. The incubation period in Double Curled parsley was 37 days, the average in Extra Triple Curled was 37 days, and in Fern Leaf or Moss Curled, 44.6 days. The average incubation period of the disease in Hollow Crown parsnip was 40 days.

The leafhopper completed its life cycle on all varieties of carrots except Yellow Belgian. A low population of leafhoppers was obtained on most varieties of carrots. The life cycle was also completed on Hamburg or Turnip Rooted, Single or Plain parsleys, and Hollow Crown parsnip. The insect failed to complete its life cycle on Double Curled, Triple Curled, and Fern Leaf or Moss Curled parsleys.

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