A MOSAIC DISEASE OF RADISH IN CALIFORNIA

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INTRODUCTION

A mosaic disease of the cultivated radish (*Raphanus sativus* L.) was prevalent in market gardens near San Pablo, in the San Francisco Bay section of California, during the winter months of 1933-34 and has been observed in subsequent years. Although infection was widespread, little or no damage to the plants resulted. The wild or escaped radish, a common weed along ditchbanks and waste places, according to Jepson (6), was also found to be highly susceptible and probably serves as an important reservoir for the virus in this section. In 1936, J. H. Freitag of the Division of Entomology and Parasitology, University of California, observed the disease on cultivated radish near Colma.

The results of studies on transmission, host range, and properties of the radish mosaic virus are presented in this paper.

REVIEW OF LITERATURE

A mosaic disease of radish was found in Indiana by Gardner (3) in 1925.

Ogilvie (8) observed that wild and garden radishes (*Raphanus raphanistrum* L. and *R. sativus*) were affected by a mosaic disease in Bermuda which caused distortion and frequently blisterlike areas of the leaves.

In 1933, Hino (5) reported a mosaic disease of radish on the cultivated variety Daikon in Japan.

Additional reports of virus diseases occurring on other closely related species were found, mention of which may be of interest. In 1924 Kulkarni (7) described a mosaic disease of the cultivated rattail or serpent radish (*Raphanus sativus* L. var. caudatus Alef.), known in India as Mogri. This disease, observed at Poona in 1922, caused mottling on the leaves, stems, and pods during the early stages of infection. Later symptoms consisted of blanching, blistering, and distortion of the leaves and pods, checking of flower and fruit formation, and stunting of the plants.

In 1932, Fukushi (2) listed a mosaic disease of *Raphanus macropoda* Lév. which he accredited to Takimoto (10).

A virus disease of jointed or white charlock (*Raphanus raphanistrum* L.) was reported from South Africa in 1931 by Van der Byl (16). The virus which attacked this annual weed, known as ramenas, was also found to infect turnips. Hino (5) also reported infection on this species in Japan, known there as Hama-daikon.
A mosaic disease of Daikon (Raphanus sp.) has recently been reported from Hawaii (4).

SYMPTOMS OF THE DISEASE

The symptoms produced by the radish mosaic virus discussed in this paper were identical in the field and greenhouse. Under greenhouse conditions, at temperatures ranging from 13° to 19° C., the first symptoms consist of small, roughly circular to irregular chlorotic lesions which occur indiscriminately between and adjacent to the veins (fig. 1, A). Fusion of some of these lesions is not uncommon (fig. 1, A). Within a few days, the chlorotic lesions become more numerous (fig. 1, B) and soon replace the normal, dark-green tissue, imparting a distinctly chlorotic color and a coarse mottle (fig. 1, C), in contrast to the normal, healthy condition (fig. 1, D). After 10 days to 2 weeks, the normal, dark-green tissue appears as irregularly-shaped, nonraised islands on a conspicuous, yellowish-green, chlorotic background (fig. 2). There is little or no leaf distortion, although occasionally raised, dark-green islands have been observed on radish plants in the greenhouse within a month after inoculation. Necrotic lesions and stunting of infected plants are not known to occur either in the field or in the greenhouse.

MATERIALS AND METHODS

The radish mosaic virus which was used in these studies came from a naturally infected white radish plant grown near San Pablo, Calif. By mechanical inoculation, the virus was transferred to healthy radish seedlings in the greenhouse. Subsequent monthly transfers of the virus have been made since 1934. White Icicle radish seedlings were selected as the standard test plant for recovery of the virus from infected plants and for property studies.

All inoculations were made in a greenhouse where temperatures ranged from 13° to 19° C. The methods followed were essentially those described in a recent paper (12). Mechanical inoculations were made by dusting the leaves with 600-mesh, powdered carborundum (9), and lightly rubbing with absorbent cotton dipped in juice from a diseased plant.

TRANSMISSION

The radish mosaic virus was readily transferred by rubbing. The use of carborundum (9) did not increase the percentage of transmission. As a result of numerous tests, the incubation period was determined as ranging from 9 to 18 days.

Studies on insect transmission of this disease involved the use of the cabbage aphid (Brevicoryne brassicae (L.)), the false cabbage or turnip aphid (Lipaphis pseudobrassicae (Davis)), and the green peach aphid (Myzus persicae (Sulzer)), all of which, according to Essig (1), breed naturally on radish and other cultivated and wild crucifers. Numerous, unsuccessful attempts were made to transmit the virus by means of these three species of aphids.

Tests for seed transmission were limited to seed obtained from 12 diseased radish plants which had previously been inoculated by mechanical means in the greenhouse. Seeds were planted in a flat of autoclaved soil. After 30 days, 757 plants were examined, all of
Figure 1.—Symptoms produced by the radish mosaic virus on White Icicle radish leaves after mechanical inoculation in the greenhouse at 13° to 19° C.: A, Early symptoms, consisting of small, circular to irregular, chlorotic lesions scattered indiscriminately between and adjacent to the veins; B and C, intermediate symptoms, consisting of irregularly-shaped light- and dark-green areas which collectively produce a coarse mottling; D, noninoculated control.
which were healthy, indicating that the virus is probably not seed-borne.

EXPERIMENTAL HOST RANGE

The following varieties of radish were tested in the greenhouse by mechanical inoculation and were found to be highly susceptible:

White Japanese, Round Black Spanish, Scarlet Turnip, Scarlet Turnip White Tip, Sparkler, White Icicle, and White Strasburg. No resistant varieties have been found.

By means of mechanical inoculation, the radish mosaic virus was transmitted to 19 species of plants representing 9 genera in 4 families (table 1). The symptoms produced by mechanical inoculation on some cruciferous hosts are shown in figures 3 and 4; on species of Nicotiana in figure 5. The virus was recovered from all infected plants except spinach.

Table 1.—Plants susceptible to the radish mosaic virus, as indicated by mechanical inoculation of greenhouse-grown seedlings, and symptoms characteristic of infection

<table>
<thead>
<tr>
<th>Family</th>
<th>Species and common name</th>
<th>Symptoms produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruciferae</td>
<td></td>
<td>Systemic infection. Diffuse chlorotic lesions on leaves. Do.</td>
</tr>
<tr>
<td></td>
<td>Brassica oleracea L. var. acephala DC. (kale)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. oleracea var. gemmifera DC. (Brussels sprouts)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. oleracea var. botrytis L. (cauliflower-var. February; sprouting broccoli-var. Italian Green Sprouting)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. oleracea var. capitata L. (cabbage-var. Winter Colma)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. oleracea var. caulorapa DC. (kohlrabi)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. nigra (L.) Koch (black mustard)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. alba (L.) Boiss, (white mustard)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. pe-tsai Bailey (pe-tsai)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>Chenopodiaceae.</td>
<td>Systemic infection. Chlorotic and necrotic lesions on leaves. Do.</td>
</tr>
<tr>
<td></td>
<td>Raphanus sativus L. var. longipinnatus Bailey (Chinese radish)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>B. juncea (L.) Coss. (Chinese or leaf mustard)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>C. muralis L. (sowbane or nettle-leaf goosefoot)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>Chenopodium album L. (lambsquarters or white pigweed)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>Spinacia oleracea L (spinach-var. Boomsdale)</td>
<td>Do.</td>
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<tr>
<td></td>
<td>Delphinium ajacis L. (rocket larkspur)</td>
<td>Do.</td>
</tr>
<tr>
<td></td>
<td>Nicotiana glutinosa L.</td>
<td>Do.</td>
</tr>
<tr>
<td>Solanaceae.</td>
<td></td>
<td>Systemic infection. Necrotic lesions on leaves and necrotic streaks on petioles. Do.</td>
</tr>
<tr>
<td></td>
<td>N. rustica L. var. humulis Schrank</td>
<td>Systemic infection. Chlorotic lesions. Do.</td>
</tr>
<tr>
<td></td>
<td>N. langsdorffii Weim.</td>
<td>Systemic infection. Chlorotic lesions with occasional necrotic lesions surrounded by yellow halos. Do.</td>
</tr>
</tbody>
</table>
Figure 3.—Local infection produced after 32 days on Chinese cabbage (Pe-tsai) by mechanical inoculation with the radish mosaic virus in the greenhouse at 13° to 19° C. Necrotic lesions with centers of green tissue appeared only on inoculated leaves.

Figure 4.—Systemic infection produced by mechanical inoculation with the radish mosaic virus in the greenhouse at 13° to 19° C.: A, Chlorotic lesions on February cauliflower leaf, 16 days after inoculation; B, necrotic lesions with centers of green tissue on Winter Colma cabbage leaf, 22 days after inoculation.
No infection was obtained by mechanical inoculation in 52 species of plants representing 45 genera in 25 families, as follows:

**Begoniaceae:**
- Fibrous-rooted begonia (*Begonia semperflorens* Link and Otto)

**Boraginaceae:**
- Forget-me-not (*Myosotis alpestris* Schmidt)
- Common heliotrope (*Heliotropium peruvianum* L.)

**Campanulaceae:**
- Canterbury-bells (*Campanula medium* L.)

**Caryophyllaceae:**
- Sweet-william (*Dianthus barbatus* L.)
- Babysbreath (*Gypsophila paniculata* L.)

**Compositae:**
- Head lettuce (*Lactuca sativa* L. var. *capitata* Hort.) var. Tom Thumb
- Dandelion (*Taraxacum officinale* Weber)
- Annual marguerite (*Chrysanthemum coronarium* L.)
- Shasta daisy (*Chrysanthemum maximum* Ram.)
- English daisy (*Bellis perennis* L.)
- China-aster (*Callistephus chinensis* Nees) var. Giant Branching White, wilt resistant.
- French marigold (*Tagetes patula* L.)
- African marigold (*Tagetes erecta* L.)
- Winter cape-marigold (*Dimorphotheca aurantiaca* DC.)
- Gaillardia pulchella Fong. var. *picta* Gray
- Hybrid cineraria (*Senecio cruentus* DC.)

**Cruciferae:**
- Rape (*Brassica napus* L.)
- Rutabaga (*Brassica campestris* L. var. *napobrassica* DC.)
- Annual stock (*Matthiola incana* R. Br. var. *annua* Voss) var. Fiery Blood Red
- Honesty (*Lunaria annua* L.)
- Dames violet (*Illesperis matronalis* L.)
- *Brassica integrifolia* O. E. Schulz var. *chevalieri* R. Porteres

**Cucurbitaceae:**
- Cucumber (*Cucumis sativus* L.)
Dipsacaceae:
    Mourning bride or pincushion flower (Scabiosa atropurpurea L.)

Euphorbiaceae:
    Castor-bean (Ricinus communis L.)

Geraniaceae:
    Storksbill (Pelargonium zonale Willd.)

Gramineae:
    - Corn (Zea mays L.) var. Golden Bantam
    - Flowering sage (Salvia farinacea Benth.)

Leguminosae:
    - Garden pea (Pisum sativum L.) var. Alderman
    - Broadbean (Vicia faba L.)

Lobeliaceae:
    - Lobelia (Lobelia hybrid Hort.)

Onagraceae:
    - Clarkia elegans Dougl.
    - Godetia grandiflora Lindl.

Papaveraceae:
    - Iceland poppy (Papaver nudicaule L.)
    - Oriental poppy (Papaver orientale L.)

Polygonaceae:
    - Rhubarb (Rheum rhaponticum L.)

Resedaceae:
    - Mignonette (Reseda odorata L.)

Rosaceae:
    - Geum chiloense Balb.

Scrophulariaceae:
    - Snapdragon (Antirrhinum majus L.)
    - Pentstemon or beardtongue (Pentstemon barbatus Nutt.)

Solanaceae:
    - Solanum aviculare Forst.
    - Potato (Solanum tuberosum L.)
    - Tomato (Lycopersicum esculentum Mill. var. vulgare Bailey) var. Early Santa Clara Canner
    - Current tomato (Lycopersicum pimpinellifolium Dunal)
    - Jimsonweed (Datura stramonium L.)
    - Petunia (Petunia hybrid Hort.)

Tropaeolaceae:
    - Garden nasturtium (Tropaeolum majus L.)

Umbelliferae:
    - Celery (Apium graveolens L.)

Verbenaceae:
    - Garden verbena (Verbena hybrid Voss)

Violaceae:
    - Pansy (Viola tricolor L.)

Subsequent inoculations to radish with extracted juice from inoculated plants of the above-mentioned plant species failed to cause infection.

PROPERTIES OF THE VIRUS

The results of property studies of the radish mosaic virus are shown in table 2. Virus samples, consisting of 2 cc of undiluted juice in small, thin-walled test tubes, were used in determining resistance to aging in vitro and inactivation temperature. In determining the tolerance to dilution, the virus was diluted with the required amount of distilled water. Young White Icicle radish plants were then inoculated mechanically with the different virus samples.

Samples of the radish mosaic virus were infectious for 14 days after aging in vitro at 22° C., but were inactivated after 16 days. The virus produced infection after heating for 10 minutes at 65°, but was inactivated at 68°. A dilution tolerance of 1 to 14,000 was established. In each of the three tests, 25 noninoculated radish plants served as controls and they remained healthy.
TABLE 2.—Longevity in vitro, inactivation temperature, and tolerance to dilution of the radish mosaic virus

[5 trials made with 25 plants each in all instances]

**LONGEVITY IN VITRO, 22° C.**

<table>
<thead>
<tr>
<th>Aged (hours)</th>
<th>Plants infected</th>
<th>Aged (hours)</th>
<th>Plants infected</th>
<th>Aged (hours)</th>
<th>Plants infected</th>
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<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>0</td>
<td>25</td>
<td>72</td>
<td>24</td>
<td>144</td>
<td>22</td>
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<tr>
<td>24</td>
<td>22</td>
<td>96</td>
<td>24</td>
<td>168</td>
<td>23</td>
<td>384</td>
<td>18</td>
</tr>
<tr>
<td>48</td>
<td>25</td>
<td>120</td>
<td>25</td>
<td>324</td>
<td>22</td>
<td>800</td>
<td>18</td>
</tr>
</tbody>
</table>

**INACTIVATION TEMPERATURE (10 MINUTES)**

<table>
<thead>
<tr>
<th>Temperature (°C.)</th>
<th>Plants infected</th>
<th>Temperature (°C.)</th>
<th>Plants infected</th>
<th>Temperature (°C.)</th>
<th>Plants infected</th>
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</thead>
<tbody>
<tr>
<td>50</td>
<td>25</td>
<td>60</td>
<td>20</td>
<td>68</td>
<td>0</td>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>55</td>
<td>25</td>
<td>65</td>
<td>7</td>
<td>70</td>
<td>0</td>
<td>Untreated</td>
<td>25</td>
</tr>
</tbody>
</table>

**TOLERANCE TO DILUTION**

<table>
<thead>
<tr>
<th>Dilution</th>
<th>Plants infected</th>
<th>Dilution</th>
<th>Plants infected</th>
<th>Dilution</th>
<th>Plants infected</th>
<th>Dilution</th>
<th>Plants infected</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:1</td>
<td>25</td>
<td>1:2,000</td>
<td>22</td>
<td>1:7,000</td>
<td>10</td>
<td>1:12,000</td>
<td>3</td>
</tr>
<tr>
<td>1:10</td>
<td>24</td>
<td>1:3,000</td>
<td>19</td>
<td>1:8,000</td>
<td>9</td>
<td>1:13,000</td>
<td>3</td>
</tr>
<tr>
<td>1:100</td>
<td>25</td>
<td>1:4,000</td>
<td>16</td>
<td>1:9,000</td>
<td>7</td>
<td>1:14,000</td>
<td>1</td>
</tr>
<tr>
<td>1:500</td>
<td>22</td>
<td>1:5,000</td>
<td>13</td>
<td>1:10,000</td>
<td>7</td>
<td>1:15,000</td>
<td>0</td>
</tr>
<tr>
<td>1:1,000</td>
<td>24</td>
<td>1:6,000</td>
<td>14</td>
<td>1:11,000</td>
<td>3</td>
<td>1:16,000</td>
<td>0</td>
</tr>
</tbody>
</table>

**DESCRIPTION OF THE RADISH MOSAIC VIRUS**

Transmissible by mechanical inoculation with or without powdered carborundum. Incubation period 9 to 18 days. Resistance to aging in vitro between 14 and 16 days. Inactivation temperature between 65° and 68° C. for a 10-minute exposure. Tolerance to dilution approximately 1 to 14,000. White radish (Raphanus sativus) and certain other vegetable and ornamental crucifers susceptible. Small, chlorotic lesions produced on White Icicle radish, followed by medium type of mottling. Mottled leaves later show marked bleaching. Occasional distortion and rugosity of leaves in late stages of infection. Virus lethal to Virginian stock and evening scented stock; occasionally infected spinach plants die. Local chlorotic lesions produced on leaves of Nicotiana glutinosa and N. tabacum; systemic chlorotic rings on N. rustica var. humulis, and systemic chlorotic and necrotic lesions on N. langsdorffii.

**COMPARISON OF THE RADISH MOSAIC VIRUS WITH CERTAIN OTHER CRUCIFER VIRUSES**

The radish mosaic virus can readily be differentiated from the mosaic viruses of cauliflower (12), Chinese cabbage (15), turnip (18), and annual stock (11), and from the black ring virus of cabbage (14) when compared as to symptomatology, experimental host range, and properties. In making these comparisons, both on radish and other plants, parallel series of mechanical inoculations were made simultaneously in the greenhouse. Because of space limitations, only a few of the most conspicuous differences can be discussed in detail.

On young White Icicle radish plants, the symptoms produced by the radish mosaic virus cannot be confused with those produced by the other crucifer viruses mentioned above. The cauliflower mosaic virus
causes pronounced vein clearing on the leaves of this host; the Chinese cabbage mosaic virus, vein clearing and a fine type of mottling; the mild annual stock mosaic virus, small, chlorotic lesions; while the severe annual stock mosaic virus, the turnip mosaic virus, and the black ring virus of cabbage failed to cause infection.

Marked differences in symptomatology were observed on certain other cruciferous plants in these comparative tests. For example, the symptoms of the radish mosaic virus on cabbage and cauliflower consist of numerous, somewhat diffuse, large, chlorotic lesions (fig. 4, A, B). In contrast, the cauliflower mosaic virus induced vein clearing on cabbage and vein clearing, vein banding, mottling, and necrotic lesions on cauliflower; the Chinese cabbage mosaic virus, a coarse, yellowish vein banding on cabbage and chlorotic lesions on cauliflower which are usually only visible in transmitted light; the turnip mosaic virus, chlorotic lesions with necrotic edges on cabbage but only large, diffuse, chlorotic lesions on cauliflower; and the black ring virus of cabbage, both chlorotic and necrotic lesions and marked general chlorosis on leaves of cabbage, and only chlorotic lesions on cauliflower. No infection was obtained on cabbage and cauliflower with the mild and severe mosaic viruses of annual stock.

On Chinese cabbage, the radish mosaic virus induced chlorotic and necrotic lesions with vein necrosis on inoculated leaves only. The cauliflower mosaic virus caused vein clearing; the Chinese cabbage mosaic virus, vein clearing and mottling; the turnip mosaic virus, coarse yellow vein banding and leaf distortion; the mild mosaic virus of annual stock, a mild, diffuse, and somewhat coarse type of mottling; and the black ring virus of cabbage, chlorotic lesions, some of which later become necrotic. The severe mosaic virus of annual stock did not cause infection of Chinese cabbage.

Purple Top White Globe turnip plants were only occasionally infected by the radish mosaic virus, the symptoms consisting of systemic mottling and severe leaf distortion. In comparison, the cauliflower mosaic virus caused vein clearing on the leaves of this host; the Chinese cabbage mosaic virus caused vein clearing and a fine type of mottling; the turnip mosaic virus, vein clearing and mottling with numerous, raised, dark-green islands; the mild mosaic virus of annual stock, a fine type of mottling; and the black ring virus of cabbage, chlorotic lesions, some of which became necrotic. The severe mosaic virus of annual stock did not cause infection of Chinese cabbage.

Other important differences between the radish mosaic virus and the other crucifer viruses mentioned are as follows: No infection of annual stock plants was obtained in numerous tests with the radish mosaic virus. The cauliflower mosaic virus induced marked vein clearing but no flower breaking on annual stock, whereas the Chinese cabbage, turnip, and cabbage black ring viruses caused leaf mottling and flower breaking. The radish mosaic virus is lethal to evening scented stock, Virginian stock, and occasionally to spinach. Large, diffuse, chlorotic lesions were produced only on inoculated leaves of Turkish tobacco and Nicotiana glutinosa, and systemic infection of rocket larkspur was obtained. Other crucifer viruses did not produce similar results.

Further, the radish mosaic virus may be differentiated from the other crucifer viruses included in these studies by its inactivation
temperature (65° to 68° C.) and its greater tolerance to dilution (1 to 14,000).

SUMMARY

A mosaic disease of radish in the San Francisco Bay section of California is described.

The symptoms of the disease consist at first of irregular-shaped, chlorotic lesions which later develop into a coarse mottle. On older, infected plants, the normal, dark-green tissue appears as irregularly shaped, nonraised islands on a yellowish-green, chlorotic background.

The radish mosaic virus is readily transmissible by mechanical inoculation, with or without carborundum. The incubation period ranges from 9 to 18 days. Unsuccessful attempts were made in the greenhouse to transmit the radish mosaic virus by means of the cabbage, green peach, or turnip aphids.

The virus retained its infectivity after aging for 14 days at 22° C. It is inactivated by heating for 10 minutes at 68°, but causes infection when diluted up to 1, to 14,000.

The host range of the radish mosaic virus includes 19 species of plants representing 9 genera in 4 families. In the family Cruciferae, infection was obtained on pe-tsai, kale, Brussels sprouts, cabbage, sprouting broccoli, cauliflower, kohlrabi, black and white mustard, evening scented stock, Virginian stock, turnip, Chinese mustard, and Chinese radish, in addition to several cruciferous weeds. Annual stock plants were found to be resistant. Other susceptible hosts included lambquarters, sowbane, spinach, rocket larkspur, Nicotiana glutinosa, N. langsdorffii, N. rustica var. humulis, and Turkish and White Burley tobacco (N. tabacum).

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