topical treatment. Selection with endrin resulted in increased tolerance to DDT and toxaphene-DDT, indicating a nonspecific type resistance factor. Adkisson (1968) reported the tobacco budworm resistant to endrin and carbaryl and suggested that it may have arisen from a cross resistance to other insecticides, namely DDT or toxaphene + DDT. Their nonspecific type resistance may be due to a physical blocking by the cuticle as opposed to a enzymatic degradation type of resistance. The injected treatments in this study show that the materials were effective if they could penetrate this cuticular barrier.

In studies by Vinson and Brazzel (1966) this particular resistant strain (SDV) of tobacco budworms differs from other resistant and susceptible strains where DDT was found to readily penetrate the cuticle.

These data indicate the danger of this type of resistance where a whole class of materials could become ineffective with the use of only 1 insecticide as opposed to the more specific enzymatic degradation type of resistance. It should be noted further that the use of a highly effective material such as endrin may result in high levels of resistance to less effective materials while the reciprocal may not be the case.

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Transmission of Rose Rosette Virus by the Eriophyid Mite Phyllocoptes fructiphilus

W. B. Allington, Robert Staples, and Glenn Vehmeyer

ABSTRACT

Rose rosette virus was transmitted by the eriophyid mite Phyllocoptes fructiphilus Koch, but not by the two-spotted spider mite, Tetanychus urticae Koch. The time necessary for the appearance of symptoms in rose plants infected by viruliferous eriophyid mites ranged from 30 to 146 days. Rosa eglanteria L., R. suffulta Greene, R. woodsii Lindl., R. multiflora Thun., and R. rubrifolia Vill. proved to be infected with rose rosette virus either by grafting or by mite transmission. R. canina L., R. gallica L., R. souleiana Crep., R. spinosissima altaica (L.), Rehd., R. hugomia Hemsl., and many interspecific hybrids including the hybrid tea, florabunda, and grandiflora complexes were observed apparently infected with rose rosette. Rose rosette evidently is a disease of rural or mountainous areas, regions where cultivated roses may be infected by mites wind-borne from infected wild rose.

For many years, a rose-breeding program was maintained at the University of Nebraska substation at North Platte, Nebr. The large nursery, consisting of 4 or 5 acres of rose-breeding stock, was situated in a rural area approximately 3 miles south of the South Platte River along which grew native wild rose. By 1959 so many plants in this nursery were afflicted with a condition causing rosetting and virtual elimination of flowering that the breeding program and the existence of the nursery were threatened by the necessity of roguing so many affected plants. An investigation was initiated to determine the cause and mode of transmission of the malady. Because certain species of eriophyid mites can either affect plants toxigenically or infect plants with viruses, the eriophyid mite species on roses immediately became suspect. The conjecture that eriophyid mites were associated with the rose abnormality was fortuitous, because evidence acquired sporadically during the next few years showed that a species of eriophyid mite was the vector of a virus causing rosetting of roses. That the disease arose through virus infection rather than by a toxigenic effect from mite feeding was established by making successful grafts from diseased to healthy plants.

SYMPTOMS OF THE DISEASE.—In the transmission trials and grafting attempts, Rosa multiflora was the rose species usually employed. A common phenomenon of the disease on this species was the breaking of most or all the axillary buds on an otherwise normal stem. The symptoms first showed in a new shoot arising usually from a basal axillary bud. Such shoots then developed consecutively toward the stem apex and frequently grew at an accelerated rate. They were thicker than normal and usually had shortened internodes, particularly toward the shoot apex. The

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4 Emeritus Assistant Professor of Horticulture.
leaves emerging on these shoots might be normal in size and shape basally, but apically they were small and misshapen. Short secondary shoots bearing very small leaves usually emerged from the axillary buds of affected shoots. This shoot proliferation with the crowding of nodes and leaves produced a witches' broom or rosetted appearance in infected plants. If infection occurred in young plants, such plants were considerably dwarfed. There was no proliferation of thorns on infected *R. multiflora*.

One of the striking symptoms on *R. multiflora* was the bright red color of the leaves. This red pigmentation could occur over the entire leaf or on part of the leaflets. Leaves without this red pigment usually exhibited a degree of interveinal chlorosis. Fig. 1 shows various aspects of the disease on *R. multiflora*.

Another rose species from which viruliferous mites were obtained and which was successfully infected by viruliferous mites was *R. rubrifolia*. The symptoms noted on *R. rubrifolia* were identical to those of rose rosette on this species as described by Thomas and Scott (1953), “misshapen leaflets and flower parts if present, dwarfing of stems, precocious growth of lateral buds, an indefinite chlorotic pattern in leaves and an increase in thorniness of affected stems.”

Viruliferous mites from *R. eglanteria*, *R. suffulta*, and *R. woodsii* also infected healthy rose test plants. Infected shoots of *R. eglanteria* were thicker than normal and had ruffled and somewhat chlorotic rosetted leaves, particularly at the shoot apex. There was no increase in thorniness in this species. Infection in *R. suffulta*, on the other hand, led to a great proliferation of thorns so that affected shoots appeared furled. There was the usual marked shortening of internodes with the development of the usual rosette. The terminal leaves on affected shoots were somewhat chlorotic but otherwise normal. Infection in *R. woodsii* also produced thorn proliferation but not to the same extent as in *R. suffulta*. Some of the leaves on this species had an indistinct chlorotic mottle. The rosette leaves at the apex of an infected shoot were puckered, small, and misshapen.

**VIRUS IDENTITY.**—As already noted, the symptom expression of rose rosette on *R. rubrifolia* described by Thomas and Scott (1953) is identical to that we obtained on the same species. Thomas and Scott noted too that rose species may vary in symptom expression but that all species exhibit precocious growth of lateral buds and shortening of internodes, a condition resulting in the typical rosette. They found also that certain infected rose species had misshapen leaflets or an indefinite chlorotic pattern in leaves or an increase in thorniness. They discovered too that grafted plants developed strong symptoms in 3–14 months in at least some parts of the plants. Although no opportunity was afforded to compare Thomas' and Scott's rose rosette virus with the Nebraska virus in size and morphology of virus particles, serological relationships, and vector transmission, in view of the great similarity in symptom expression, the uniqueness of the disease, and comparable results in successful grafting attempts, we conclude that in all likelihood Thomas and Scott and we worked with the same virus—that causing rose rosette.

**MECHANICAL INOCULATION OF ROSE ROSETTE VIRUS.**—Mechanical inoculations were made by grinding leaves from either naturally infected or graft-infected rose plants and rubbing the juice, either with or without phosphate buffer, on leaves of very small rooted cuttings of *R. multiflora* or seedlings of cucumber, squash, and cowpea. All such inoculations were completely negative.

**HOSTS OF ROSE ROSETTE VIRUS.**—The following rose species or cultivars have been definitely proved to be...
Table I.—Experimental conditions and results obtained in transmission trials with the eriophyid mite Phyllocoptes fructicophilus, and the two-spotted spider mite, Tetranychus urticae.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Date of mite transfer</th>
<th>Source of mites</th>
<th>No. collections</th>
<th>No. mites/test plant</th>
<th>No. test plants infected from each collection</th>
<th>No. test plants infected</th>
<th>Symptom appearance (days)</th>
<th>Date negative test plants discarded</th>
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<tbody>
<tr>
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<tr>
<td></td>
<td></td>
<td>R. montezumae</td>
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<td>50</td>
<td>1</td>
<td>0</td>
<td>12/11/59</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td>1</td>
<td>0</td>
<td>12/11/59</td>
<td></td>
</tr>
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<td>12/7/59</td>
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<td>0</td>
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<tr>
<td></td>
<td></td>
<td>R. montezumae</td>
<td>1</td>
<td>50</td>
<td>1</td>
<td>0</td>
<td>5/6/60</td>
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<td>9/27/65</td>
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<td>10</td>
<td>11</td>
<td>1</td>
<td>82</td>
<td>3/30/66</td>
</tr>
</tbody>
</table>

Trials with Tetranychus urticae

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Date of mite transfer</th>
<th>Source of mites</th>
<th>No. collections</th>
<th>No. mites/test plant</th>
<th>No. test plants infected from each collection</th>
<th>No. test plants infected</th>
<th>Symptom appearance (days)</th>
<th>Date negative test plants discarded</th>
</tr>
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<td>2/7/64</td>
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<td>1/4/65</td>
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<tr>
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<td></td>
<td>R. canina</td>
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<td>10</td>
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<td>0</td>
<td>1/4/65</td>
<td></td>
</tr>
<tr>
<td>10</td>
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<td>26</td>
<td>0</td>
<td>0</td>
<td>6/14/65</td>
<td></td>
</tr>
</tbody>
</table>

Infected with rose rosette virus either by grafting or by mite transmission:

- R. eglanteria L.
- R. sulphula Greene
- R. woodsi Lindl.
- R. multiflora Thun.
- R. rubrifolia Vill.
- R. niutana Presl.
- R. odorata Sweet.
- R. pisocarpa Gray
- Belle of Portugal
- Ragged Robin

The following rose species or cultivars have been observed by one of us (Viehmeyer) to be apparently infected with rosette virus either in the rose nursery at North Platte, Nebr., or in a nursery at the Morden Experiment Station, Morden, Manitoba, Canada:

- R. canina L. (North Platte, Morden)
- R. gallica L. (North Platte)
- R. soulieana Crép. (L.) Rehd.
- R. hugonis Hemsl.

Hybrids with R. eglanteria (North Platte, Morden)
Hybrids with R. multiflora
Cultivars of hybrid teas, florabundas, and grandifloras

MITE TRANSMISSION TRIALS.—Mites were usually obtained from rose cuttings collected from apparently infected plants in the field. A collection consisted of cuttings removed from a single plant. Mite-infested cuttings of R. woodsii were taken from thickets along the South Platte River; cuttings of other species and cultivars (unless otherwise noted) were removed from plants in the North Platte Experiment Station nursery. Periodic determinations of the eriophyid species involved. Eriophyid mites were transferred to test rose plants with a single-hair camel's-hair brush. The test plants were positioned under a dissecting microscope so that mites could be deposited in a leaf axil and observed as they crawled away.

Attempts were made to develop eriophyid mite cultures in the greenhouse, but either the eriophyids did not survive or the culture plants became so infested with tetranychid mites that they had to be discarded. Infestation of test plants or culture plants with tetranychid mites, almost a certainty in the greenhouse, was a wearisome problem because of the inability to control tetranychids chemically without also eliminating the eriophyids.

In all transmission trials, except one, the mite-infested test plants and several uninfested control plants were kept in the same greenhouse section. No control plant ever became infected.

Table 1 presents the experimental conditions and results of the transmission trials. R. eglanteria was the test plant species in the 1st 2 trials; R. multiflora test plants were used in all other trials. In trial 1, the test plants were examined for eriophyids before being discarded. Mites found on 3 test plants were moved to further test plants in trial 2. Two of the
Fig. 2.—*P. fructiphilius*. API, interior structures of female genitalia; DA, dorsal view of anterior end; ES, detail of side skin; F, featherclaw; GFI, female genitalia and coxae; L, left legs or parts of left legs; S, side diagram of mite. (Courtesy of Mr. H. H. Keifer.)

3 test plants in trial 2 were also found eriophydid-infested immediately before they were discarded. These mites had been maintained from September 1959 to May 1960, the longest time ever achieved under greenhouse conditions.

The collection in trial 5 was obtained from an infected plant of a wild rose, *R. suffulta*, growing close to the Dismal River in rural central Nebraska.

In trials 8, the test plants, before and after eriophydid infestation, were grown in an environmental control room at a temperature of 75°F. This method avoided any possibility of infestation of the test plants with any insect or mite other than the experimental eriophydid.

In trials 1-7, the test plants eventually became infested with the two-spotted spider mite, *Tetranychus urticae* Koch. In trial 9, nine test plants were infested by brush transfer with two-spotted spider mites from a graft-infected *R. multiflora* after the mites had been on the virus source for 1 day; 6 test plants after 2 days; 4 test plants after 4 days; 2 test plants after 6 days; and 3 test plants after 11 days. Five test plants were infested with mites from a naturally infected *R. carinae* after the mites had been on the virus source for 1 day; 1 test plant after 2 days; 1 test plant after 6 days; and 2 test plants after 17 days. All test plants were sprayed with chlorobenzilate 35 days after mite transfer to prevent the mites from completely defoliating the plants.

In trial 10, the test plants were infested with two-spotted spider mites from a graft-infected *R. multiflora* plant. Mites were transferred by placing 1 or 2 mite-infested leaves on the upper leaves of each test plant.

In all these trials, 11 test plants were infested of the 38 infested with eriophyids. The time necessary for the appearance of symptoms ranged from 30 to 146 days. None of the 59 test plants infested with two-spotted spider mites from diseased plants became infected.

**IDENTITY AND BIOLOGY OF THE VECTOR.—From specimens sent to him on 3 occasions, Mr. H. H. Keifer identified the vector of rose rosette virus in Nebraska as *Phyllocopetes fructiphilius* Koch (Fig. 2). Males were discovered among the specimens examined by Mr. Keifer. From all appearances, *P. fructiphilius* has a typical eriophydid biology consisting of the egg, 2 nymphal stages, and the adult. During the growing season, all stages are commonly found in the angles between the leaf petioles and the axillary buds, particularly toward the shoot apex. Keifer (1940) reports this species as an inhabitant of rose fruits. A cursory examination of a few rose hips failed to reveal any mites, but mites could be found beneath the bud scales during the winter and early spring. Evidently this species overwinters in any protected place on the rose plant. In early spring the mite population is low and mites do not become numerous until mid-June and early July. The population increases until it reaches a peak in September. In Nebraska, mites are frequently found in considerable numbers on roses in early December.

**EPIDEMIOLOGY OF ROSE ROSETTE.—**Thomas and Scott (1953) report the occurrence of rose rosette in an ornamental shrub at the State Training School, Lander, Wyo. The same disease was found nearby in an unidentified native rose. In California, the disease was discovered in a native rose near Carville in a mountainous area. According to Nichols (1966), Traylor and Williams identified rose witches' broom (rosette of rose) in 4 plants of wild rose growing in a mountainous region of California. In Nebraska, except for a single diseased plant discovered in the city of Kearney, rose rosette has occurred only in rural areas in cultivated roses at North Platte and in native roses along the Platte and Dismal Rivers. It has been observed also in a rose nursery at Morden, Manitoba, also a rural area.

Apparently the reservoir of rose rosette virus exists in wild rose, and infection becomes established in cultivated roses by wind-borne eriophyds from this reservoir. Further infection could occur in cultivated roses by the movement of viruliferous mites from plant to plant and, according to Viehmeyer, possibly by root grafts. As the reports on disease incidence indicate, rose rosette is principally a disease of rural and mountainous regions, places where cultivated roses can more readily be infected with viruliferous mites from the wild rose reservoir. It is unlikely therefore that rose rosette will be troublesome on cultivated roses in urban and metropolitan areas.

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