STRAWBERRY VIRUSES[1]

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Introduction

The majority of strawberry viruses do not produce, on commercial varieties, symptoms that are sufficiently characteristic to allow positive identification in the field. Transmission to indicator plants is necessary for the detection and identification of these viruses,

When, as often happens, more than one virus is present, the separation of the components of the mixture can sometimes be achieved by making use of differences in their vector relationships or differences in their stability when the plants are grown at high temperatures.

Before entering upon a detailed description of the various viruses, it will be useful to make some general comments on the indicators and techniques we have 'used in our studies in British Columbia.

INDICATOR PLANTS

Several strains of the wild strawberry, *Fragaria vesca* L., are used as indicators. No one of these strains is adequate for the detection of all the known strawberry viruses but, by using discrimination, a minimum number of indicators may be selected for a complete indexing program,

East Malling clone of Fragaria vesca (E M C)

This clone was originally selected at East Malling, England, because of its sensitivity to mottle viruses. This sensitivity is now known to be due to the presence of latent-A virus with which the clone is infected. The East Malling clone is a good indicator for mottle viruses, for veinbanding, and for latent-C, but it is less sensitive to mild yellow-edge than some of the other indicators. It is a poor indicator for crinkle because latent-A is apparently a strain of, and affords partial protection against, the crinkle virus.

Alpine Fragaria vesca seedlings

The Alpine *Fragaria vesca* is a runnerless strain grown from seed, The seedlings are not entirely uniform in their reaction to any given virus isolate. They are satisfactory indicators for mild yellow-edge and for severe strains of mottle or veinbanding, but are poor indicators for mild strains of mottle and veinbanding. They are not sensitive to latent-C virus.

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Frazier' s runnerinn alpine seedling (U C 1)

This is a runnering strain of F. vesca, selected by N. W. Frazier of Berkeley, California. This clone was developed from an Alpine seedling and it is assumed to be a hybrid of Alpine and East Malling F. vesca. It is a good indicator for both crinkle and mild yellow edge. It is not sensitive to latent-C, and is less sensitive to mottle and veinbanding than is the East Malling clone of F. vesca.

Miller' s virus-free Fragaria vesca

This clone was selected by Paul W, Miller at Oregon State College. It probably arose from a seedling of the East Malling F. vesca. It is free of latent-A virus, and symptoms on this indicator are similar to those on Frazier' s U C 1 clone.

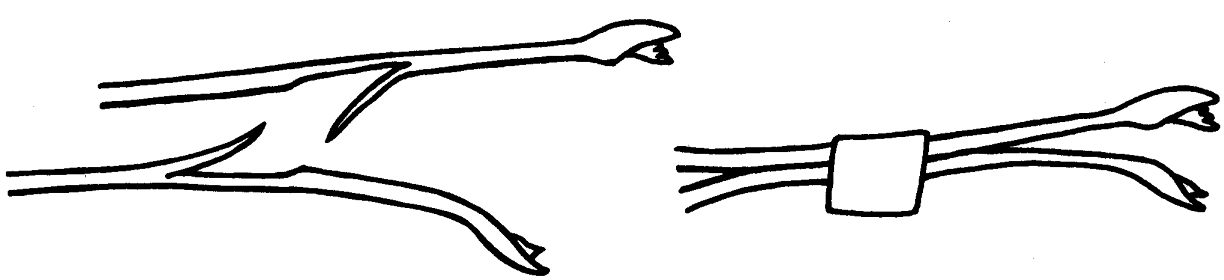
Fulton' s latent-free Fragaria vesca (E M K)

This is a clone developed by J.P. Fulton of Arkansas, from a plant of the East Malling clone which he had freed of latent-A by heat treatment. Symptoms of mild yellow edge and latent-C on this indicator are similar to those on the East Malling clone, Symptoms of mottle and veinbanding are similar to those on Frazier' s U C 1 and Miller's clone.

TECHNIQUES

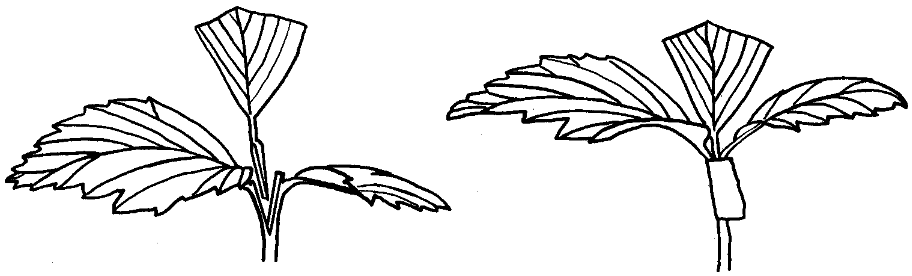
Grafting

Runner grafting, described by Harris and King (14), has been widely used for the experimental transmission of strawberry viruses. If this technique is used in indexing commercial stock, a non-grafted sister plant should be used for propagation because of the possibility of transmission of a latent virus from an infected indicator.



In runner grafting, young stolons from the donor and indicator plants are grafted together as shown above. A slanting cut, about three quarters of an inch long, is made in each of the stolons. The cut is made toward the stolon tip of the donor plant, and toward the stolon base of the indicator plant. The cut surfaces are fitted together and bound with raffia, scotch tape, or, preferably, with a self-sealing elastic bandage.

The leaf insert method of graft indexing, described by Bringhurst and Voth (1), has several advantages: no runners are required so that indexing can be done at any time of year; fewer donor plants are required for replicated indexing; and there is no danger of contaminating the donor plant with a latent virus from the indicator.



In leaf insert grafting, a leaf is detached from the donor plant. The side leaflets are removed and, if the leaf is large, most of the center leaflet cut off. The petiole is cut to wedge shape, half to three quarters of an inch long. On the indicator a center leaflet is removed from a young leaf and the petiole is split to correspond to the wedge on the donor leaf. The donor leaf is inserted snugly into this split and bound as for runner grafting. At least two leaflets should be inserted in each indicator. Survival of the inserted leaves for three weeks or more indicates successful graft union.

It should be emphasized that neither of these techniques, even where the union remains sound for many weeks, will assure transmission from an infected plant. Only repeated indexing will give any assurance that a given plant is virus-free.

Aphid transmission

The use of vectors in indexing is usually confined to those cases where the presence of a complex of viruses is suspected and it is desirable to separate the components.

Viruses that are aphid-transmissable may be separated from those that are not by the use of aphids. Furthermore, viruses that differ in their persistence may be separated from mixtures by varying the acquisition and transfer feeding periods, and by making serial transfers over a period of several days. Finally, certain aphid species may transmit one virus more efficiently than another and, by using selected vectors, individual viruses may be separated from a mixture.

The most important vectors of the strawberry viruses are members of the genus *Pentatrichopus*. Because of the difficulty of distinguishing between species of this genus, we have used clonal lines of aphids for most of our vector work in British Columbia.

A colony of virus-free aphids is easily established if two facts are born in mind: first that the young aphids do not acquire the virus directly from a viruliferous mother; and second that the nymphs do not start to feed for several hours after they are born. However, moving a newly born nymph without killing it is difficult. Our method of obtaining non-viruliferous colonies is as follows: an adult is transferred to a detached leaf and observed at intervals of one or two hours. As each nymph is born, the leaf piece on which it rests is cut out and transferred to a fresh leaf from a virus-free plant. The nymphs move off the wilting leaf pieces before they start to feed and so will establish a clone that is certain to be virus-free.

Heat treatment

A number of strawberry viruses can be elminated by heat treatment. Mottle is the most heat-labile and is usually inactivated by growing infected plants at 100°F. for 2 weeks, a period which most varieties will withstand. Other viruses are eliminated only after such prolonged treatment that survival of the treated plant becomes uncertain,

Strawberry varieties differ in their ability to survive heat treatment, but in addition to inherent varietal differences, the condition of the plant, and the way it is handled during treatment, also affect survival. Plants should have well developed roots, even to the extent of being somewhat pot bound. Humidity should be low; 40 to 50% is adequate. Soil moisture should be kept to the minimum necessary to prevent wilting; overwatering, or allowing the pots to stand in water, will reduce survival. Evaporation from unprotected clay pots may reduce soil temperature as much as 10°F below the air temperature, and attempts to correct this by wrapping the pots in aluminum foil or plastic, or by using plastic pots, hasten plant mortality. According to Posnette and Cropley (22) removal of older leaves from the plants before treatment also shortens the period plants will survive.

It may be that plants will survive longer at a fluctuating temperature than at a constant temperature. The standard heat treatment is at a constant temperature of 100°F. We have had considerable success, however, using a heat chamber in which the daily temperature fluctuates from 95° to 115°F. Plants continue to grow actively in this chamber, and commonly survive for 3 or 4 months. One plant survived 8 months of treatment. We have succeeded in inactivating five viruses under these conditions. We have repeatedly eliminated mottle and latent-A viruses and, in a few instances, crinkle, witches' broom, and veinbanding.

The length of treatment required for virus elimination can be reduced by propagation of cuttings from treated plants. Posnette and Jha (24) describe propagation by slicing the crown of the treated plant into discs 0.5 or 1 cm. thick, and planting the discs in sand or peat. By this method they developed plants free of crinkle virus after only 2 or 3 weeks treatment whereas, in previous experiments, they had found a 50-day heat treatment necessary for the inactivation of this virus. Unfortunately, heat treatment decreased the proportion of cuttings that became established and, in one trial where 52 cuttings were made from plants treated for 2 weeks, only 5 survived.

We use another method of propagation. Small axillary buds are excised and rooted in sand under mist during, or very shortly after, heat treatment of the parent plants. By this method we have developed plants free of latent-A virus after 5 weeks treatment, whereas this virus is not eliminated from the parent plant by a 3-month heat treatment. Plants a year or more old are the most suitable for this type of treatment. On such plants, axillary buds frequently develop on the older part of the crown and can be removed during treatment as they reach the desired stage of development. The smaller the bud excised, the more likely it is to be virus-free but buds weighing less than 20 mg. do not root readily. Furthermore, the development of at least a partially expanded leaf on the excised bud appears to be necessary for survival. The length of heat treatment has no adverse effect on rooting. We have established plants from buds excised after treatment periods of 4 months.

The apparent recovery of plants during heat treatment may be deceptive. Plants of the more heat-tolerant varieties, treated under optimum conditions, will continue to grow during treatment. On plants infected with viruses which cause symptoms, new leaves formed during treatment may be symptomless so that, with the death and removal of older leaves, the treated plants appear normal. After treatment, the re-appearance of symptoms may take much longer than expected on those plants in which the virus was almost, but not quite, inactivated. Plants developed from excised buds may remain symptomless even longer than the parent plants, and the smaller the excised bud, the longer the new plant will remain symptomless.

Posnette and Cropley (22) report ,that some plants infected with yellow edge virus remained symptomless for more than a year after treatment., and then symptoms reappeared,

We have found a similar, although less extreme, delay in the re-appearance of symptoms. In studying the elimination of latent-A virus by heat therapy, we used test plants infected with veinbanding and latent-A viruses, a combination which causes severe symptoms on commercial varieties, and from which elimination of latent-A is indicated by loss of symptoms from the treated plant. Some of the plants developed from excised buds appeared normal as long as 12 weeks before symptoms again appeared. All the plants that appeared normal at the end of that time, however, were still normal 3 years later, and it is assumed that latent-A was completely eliminated from these,

The reappearance of crinkle symptoms was similarly delayed on plants developed from excised buds. One plant, developed from an axillary bud, appeared normal for 4 months before crinkle symptoms reappeared, although the parent plant from which this bud was taken again showed symptoms 3 weeks after treatment.

With such experience it follows that, when latent viruses are involved, results should be interpreted with a great deal of caution. Indexing should be repeated over a long period of time before any treated plant is pronounced virus-free.

NOTE ON SOIL-BORNE VIRUSES INFECTING STRAWBERRY

A number of soil-borne viruses, whose principal hosts are other plants, have been shown to infect strawberry in Britain and Europe. With the exception of tobacco necrosis virus (6 and 11) there are no similar reports from North America, although the extent of survey has admittedly been limited.

Summarizing the situation in Britain, Lister (15) reports that all the isolates of soil-borne viruses infecting strawberry that were collected in England have proved to be strains of arabis mosaic virus, whereas almost all collected in Scotland have been strains of tomato black ring and raspberry ringspot viruses.

The soil-borne viruses are not discussed in this review.

MOTTLE VIRUS, Thomas (30)

What is described here as strawberry mottle virus is evidently a group of viruses or virus strains which have similar vector characteristics and similar responses to heat therapy but which produce a very wide range of symptoms on Fragaria vesca.

SYNONYMS: Virus I (mild crinkle), Prentice and Harris (28)
Type I, Demaree and Marcus (3)
"Non-persistent component of yellows", Mellor and Fitzpatrick (18)

GEOGRAPHIC DISTRIBUTION: World wide.

SYMPTOMS: On commercial varieties there are no reliable symptoms but there is good evidence that some strains depress vigor.

On Fragaria vesca symptoms range from an almost undetectable mild mottling to severe stunting accompanied by various types of leaf distortions.

The first symptoms appear on the youngest leaf 10 to 20 days after inoculation. The petiole of this leaf is short, and one or two leaflets are reflexed and smaller than normal. These leaflets become mottled, crinkled, cupped, or otherwise distorted depending on the strain of the virus present. Subsequent leaves show the symptoms that are characteristic of that particular strain, although there may be minor fluctuations in their intensity depending on growing conditions and season of the year.

COMPLEXES WITH OTHER VIRUSES:

Mottle viruses combined with mild yellow edge virus produce xanthosis or yellows in susceptible commercial varieties and in F. vesca.

Mottle and latent-A viruses combined cause no diagnostic symptoms in commercial varieties, but vigor is depressed even further than by mottle alone.

Similarly, mottle and veinbanding combined cause no symptoms on the commercial varieties although again there is a greater depression of vigor than with either virus alone. In F. vesca, the mottle symptoms usually mask the veinbanding although the combined effect is greater than that of either virus alone,

TRANSMISSION is mainly by aphids of the genus Pentatrichopus: P. fragaefolii (Cock.), P. thomasi Ris Lambers, and P. thomasi ssp. jacobi Ris Lambers at the Pacific Coast; and P. minor (Forbes) in Eastern North America.

Aphids can acquire the virus from an infected plant within an hour but vector efficiency increases with longer feeding periods. The aphids usually lose their virus charge within 6 hours of leaving the source plant. There are differences in the efficiency of clonal lines of aphids, and the milder strains of the virus are sometimes difficult to transmit.

Other aphids that have been reported as vectors of mottle virus are: Acyrthosiphon malvae ssp. rogersii (Theob.), Amphorophora rubi (Kalt.), Aphis gossypii Glover, Macrosiphum pelargonii (Kalt.), Myzaphis rosarum (Walk.), Myzus ascalonicus Doncaster, M. ornatus Laing, M. porosus Sanderson, and Pentatrichopus tetrarhodus (Walk.).

HEAT INACTIVATION:

Mottle viruses can usually be eliminated by growing infected plants at 100°F for 10 to 14 days.

DETECTION AND IDENTIFICATION:

The East Malling strain of Fragaria vesca (E M C) is the most sensitive indicator for the mottle viruses. This strain is infected with strawberry latent-A virus which intensifies the symptoms of mottle.

Where the presence of other viruses is suspected, the plants should be heat-treated to eliminate the mottle viruses and allow the identification of any accompanying viruses.

REFERENCES: 3, 9, 16, 18, 19, 22, 23, 28.

ILLUSTRATIONS:

Fig. 1. Primary symptoms of mottle in East Malling F. vesca
Fig. 2 Chronic symptoms of mild mottle in East Malling F. vesca
Fig. 3. Chronic symptoms of moderately severe mottle in East Malling F. vesca
Fig. 4. Chronic symptoms of severe mottle in East Malling F. vesca (see also Figs. 5 and 6)

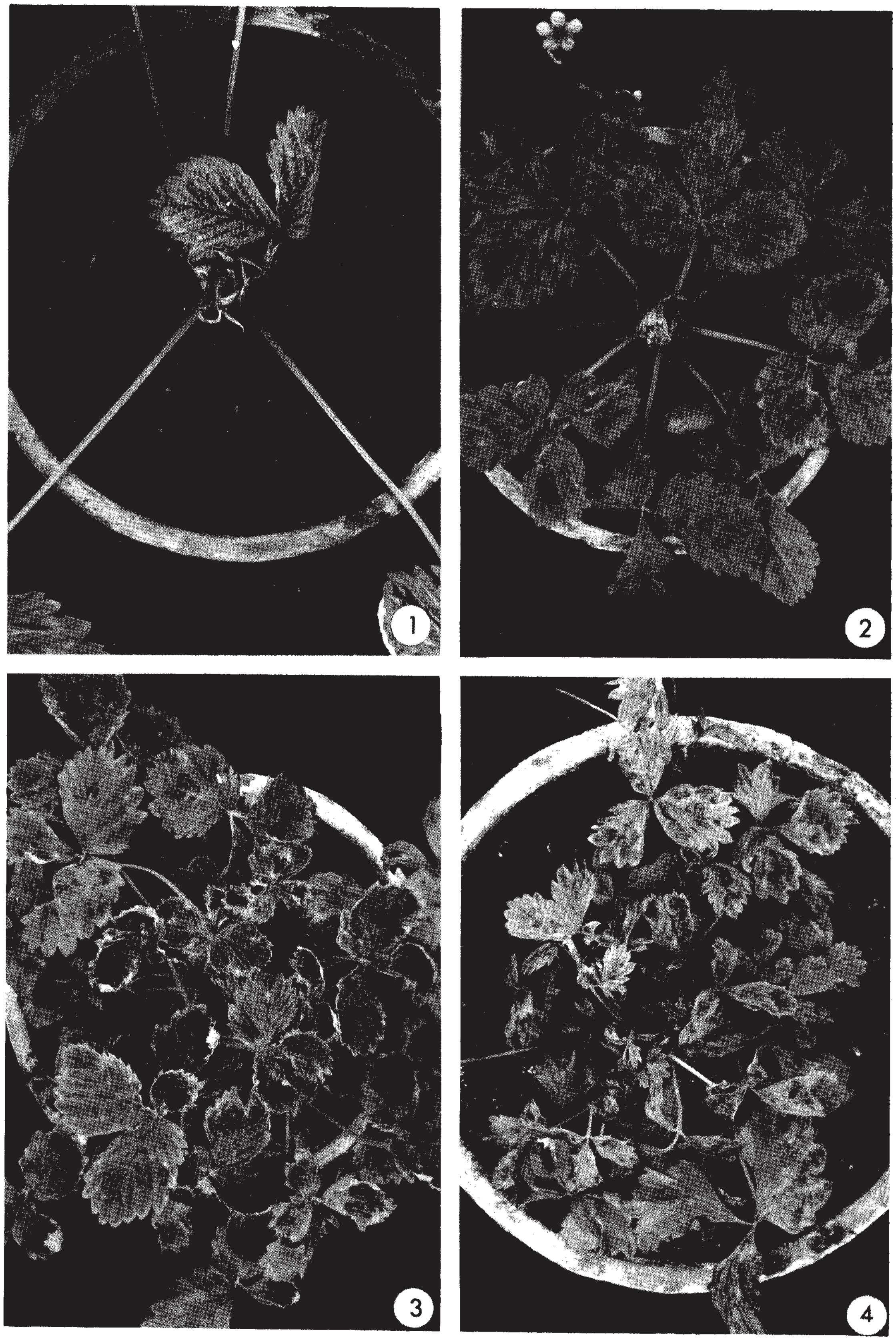
STRAWBERRY LATENT-A VIRUS, Frazier and Posnette (9)

SYNONYMS: Strawberry latent virus, strain A., Frazier (4).

Note: According to Fraeier and Posnette (9) this virus affords partial protection against the strawberry crinkle virus'es and consequently can be considered as a strain of these. However, because of its importance, it is treated here as a separate virus.

GEOGRAPHIC DISTRIBUTION:

Little is known of the natural distribution of strawberry latent-A virus. It was originally found by Fraeier in the strain of East Malling Fragaria vesca that Prentice and Harris had selected for its unusual sensitivity to the mottle viruses. Frazier also found a similar virus in a number of clones of F. californica growing in widely separated localities in the Coast Range mountains of California, and in a number of nursery colonies of apparently normal plants of the Marshall variety.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Wherever else it has been found, it is assumed to have been introduced into stock that has been indexed by runner grafting to East Malling F. vesca.

SYMPTOMS: Strawberry latent-A virus causes no symptoms, either on commercial varieties or on F. vesca. Its presence is detected by its influence on the symptoms of mottle or veinbanding viruses.

COMPLEXES WITH OTHER VIRUSES:

Latent-A and mottle viruses combined depress the vigor of commercial varieties but cause no tangible symptoms. In F. vesca, latent-A increases the severity of the symptoms of any particular mottle strain to those of a more severe strain.

Latent-A and veinbanding combined cause severe symptoms on commercial varieties and on F. vesca (see veinbanding virus).

TRANSMISSION is by grafting only; no vector has been found.

HEAT INACTIVATION:

Strawberry latent-A virus will survive in plants heat-treated for 3 months. It can be eliminated, however, by propagation of axillary buds excised from heat-treated plants. We have developed plants free of this virus from buds weighing up to 85 mg., excised after 5-weeks treatment, and from larger buds after longer treatment. Virus-free buds were excised up to 3 weeks after the end of the treatment.

DETECTION AND IDENTIFICATION:

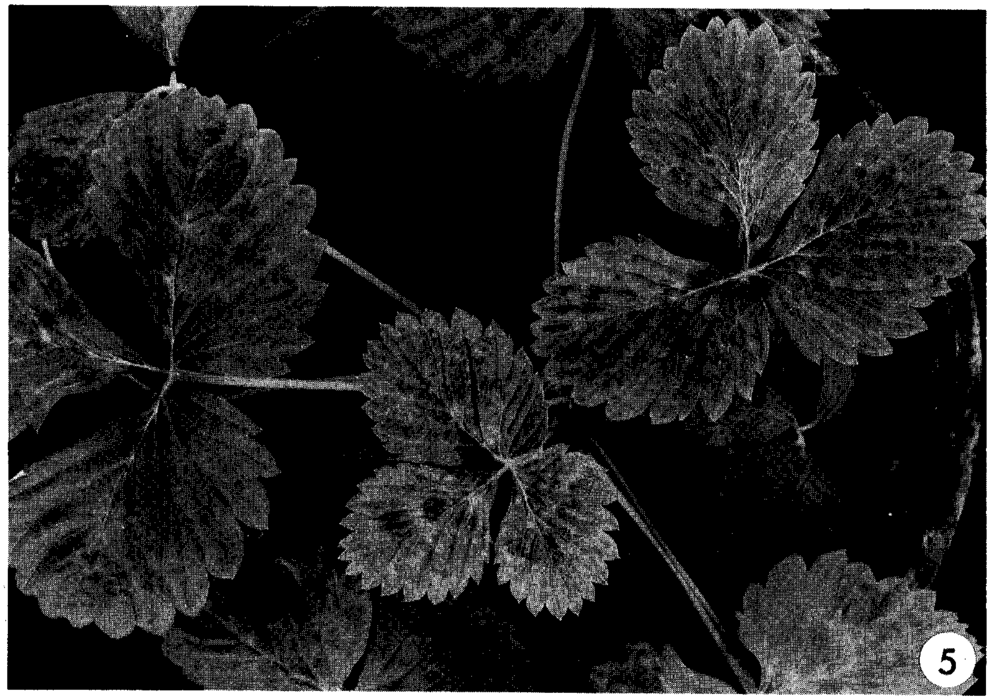
Strawberry latent-A virus can be most easily detected by grafting to an indicator that is carrying veinbanding virus. The complex of the two viruses will produce the leaf distortion shown in Figs. 9 and 10.

REFERENCES: 4, 9, 16, 19.

ILLUSTRATIONS:

Fig. 5. Miller's latent-free F. vesca with mild mottle
Fig. 6. Miller's latent-free F. vesca with mild mottle and latent-A

(see also Figs. 8, 9 and 10)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VEINBANDING VIRUS. Frazier (5)

SYNONYMS: None, but the complex of a strain of veinbanding and strawberry latent-A virus in East Malling Fragaria vesca was described by Prentice as virus 5, or strawberry leaf curl virus (27).

GEOGRAPHIC DISTRIBUTION:

Occurs on both the Pacific and Atlantic Coasts of North America. It does not appear to occur naturally in Great Britain (Prentice's isolate was from a plant imported to England from the U.S.A.).

SYMPTOMS: On commercial varieties: There are no diagnostic symptoms although some strains may depress vigor slightly.

On Fragaria vesca: Symptoms appear 4 to 6 weeks after inoculation as discontinuous chlorotic streaks along the midribs and some secondary veins. Vigor is moderately reduced, The clarity of the veinbanding symptom fluctuates greatly and, particularly following transplanting or application of fertilizer, infected plants sometimes produce a series of symptomless leaves.

COMPLEXES WITH OTHER VIRUSES:

Veinbanding and latent-A viruses combined cause severe symptoms both on commercial varieties and on the indicators. On commercial varieties the leaves are twisted due to the shortening of portions of the veins. Chlorosis or purpling develops along the veins and dark purple lesions appear on the petioles. Vigor is much reduced. On F. vesca, the symptoms are similar but there is less purpling of the veins and more twisting of the leaves.

TRANSMISSION is by several aphid species representing a number of different genera, Vectors reported to date are: Amphorophora rubi (Kalt.), Aulacorthum solani (Kalt.), Aphis idaei van der Goot[4], Macrosiphum pelargonii (Kalt.), M. rosae (L.), Myzus ascalonicus Doncaster, M. ornatus Laing, M. persicae (Sulz.), Pentatrichopus fragaefolii (Cock.), P. tetrarhodus (Walk.), P. thomasi Ris Lambers, and P. thomasi spp. jacobi Ris Lambers.

Virus-vector relationships are similar to those of the mottle viruses. The aphids can acquire the virus from a source plant in 30 minutes but efficiency increases with longer feeds. Persistence in the vector is relatively short, being usually less than 6 hours. There are differences in the efficiency of clonal lines of aphids, and there is evidence that some aphid species will transmit some strains of veinbanding but not others (19).

[4]The vector referred to by Mellor and Forbes (19) as Aphis rubifolii (Thomas) has since been identified as Aphis idaei van der Goot.

HEAT INACTIVATION:

Veinbanding is one of the more heat-stable viruses and its inactivation by heat has not previously been reported. We have found that it survived in plants treated for periods up to 8 months. We have one plant, however, from which veinbanding has been eliminated. This plant arose from an axillary bud after the parent plant was apparently killed by a 6-month heat treatment. Indexing this plant 18 months after the end of the treatment still failed to demonstrate the presence of the virus,

DETECTION AND IDENTJFICATION:

Since it is difficult to detect the veinbanding virus in the presence of strawberry mottle virus, plants to be indexed should first be heat-treated to remove the mottle viruses. The presence of veinbanding can then be demonstrated by transmission to indicators carrying latent-A virus, or to Alpine F. vesca.

REFERENCES: 5) 7, 9, 16, 19.

ILLUSTRATIONS:

Fig. 7. Veinbanding in Alpine F. vesca
Fig. 8. Veinbanding in Miller's latent-free F. vesca
Fig. 9. Veinbanding in East Malling F. vesca showing the downward curl and twisting of the leaflets characteristic of the veinbanding-latent A complex.
Fig. 10. Veinbanding-latent A complex in Marshall

MILD YELLOW EDGE VIRUS, Prentice (25)

SYNONYMS: Virus 2, Prentice (25)
"Persistent component of yellows" Mellor and Fitzpatrick (18)

GEOGRAPHIC DISTRIBUTION: Probably world wide.

SYMPTOMS: On commercial varieties: Because of the ubiquity of the strawberry mottle viruses, mild yellow edge seldom occurs alone under field conditions. It is virtually symptomless alone, causing little reduction in vigor and at most very slight chlorosis, mainly at the margins of the leaves.

On Fragaria vesca: Symptoms appear on plants of Frazier's U C 1 clone or on Alpine seedlings 4 to 6 weeks after inoculation, but may take much longer to appear on plants of the East Malling clone. Symptoms vary, depending on the strain of the indicator and on the strain of the virus. Plants of the East Malling clone are usually reduced in vigor with marginal chlorosis and slight cupping of the leaves, However, these symptoms are sometimes difficult to distinguish, even with healthy controls for comparison, Plants of Frazier's U C 1 clone, or Alpine seedlings, are better indicators for this virus. Symptoms on


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these indicators consist of premature reddening and yellowing of the older leaves, followed by scorching and their death.

COMPLEXES WITH OTHER VIRUSES:

Mild yellow edge and mottle viruses combined cause xanthosis or yellows in susceptible commercial varieties and in F. vesca. The economic importance of this disease in Europe and Western North America, and its lesser importance in Eastern North America are probably due to differences in the susceptibility of the different varieties grown in these areas rather than to the geographic distribution of the virus.

TRANSMISSION:

By aphids of the genus Pentatrichopus: P. fragaefolii, P. thomasi, and P. thomasi ssp. jacobi.

Aphids require acquisition and transfer feeding periods of 1 to 2 days each for transmission of this virus, and remain infective for 10 to 12 days after leaving the source plant.

HEAT INACTIVATION:

Mild yellow edge is not readily inactivated by heat therapy. Posnette and Cropley (22) report that plants were not cured by treatment at 37°C (98.5°F) for periods up to 26 days and although some plants remained symptomless for more than a year, they eventually relapsed. They did, however, obtain one runner plant, propagated immediately after treatment of the parent plant for 16 days, which was apparently virus-free two years later.

We have not eliminated this virus. Axillary buds, removed after treatment of the parent plant at 95-115°F for periods up to 3 months, were all infected.

DETECTION AND IDENTIFICATION:
Mild yellow edge can be separated from the xanthosis complex by allowing aphids to feed on source plants for several days, and then transferring them to a series of plants at daily intervals. The first plant or plants in the series will become infected with any non-persistent viruses (i.e. mottle and veinbanding) that may be present, whereas only mild yellow edge will be transmitted to plants further along the series.

The best diagnostic characters are probably the progressive reddening, yellowing, scorching, and dying of the older leaves on Frazier's U C 1 clone or on Alpine seedlings, and the ability to produce typical xanthosis when combined with mottle virus in a susceptible variety such as Marshall.

REFERENCES: 3, 9, 16, 18, 19, 22, 25.

ILLUSTRATIONS:
Fig. 11. Frazier's U C 1 F. vesca with mild yellow edge, showing the progressive scorching and dying of older leaves.
Fig. 12. Right: East Malling F. vesca with mild yellow edge
Left: East Malling F. vesca, control plant.

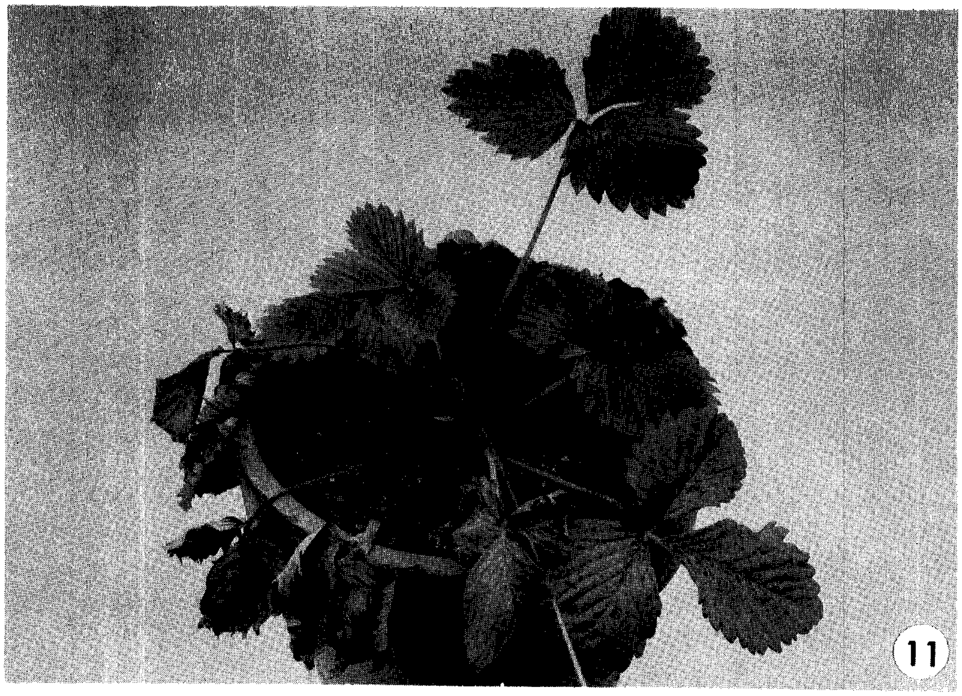
CRINKLE VIRUS Zeller and Vaughan (33)

SYNONYMS: Fragaria virus 2, Zeller and Vaughan
Virus 3, Prentice (26)
Strawberry virus 4, J. Johnson
Marmor fragariae, Holmes.

GEOGRAPHIC DISTRIBUTION: Pacific coast of North America, and Great Britain.

SYMPTOMS: On commercial varieties: The more severe strains of crinkle virus seriously reduce the vigor of plants of susceptible varieties such as Marshall. Yellow spots appear on the leaves, varying in size from pinpoints to large chlorotic areas which cause leaf distortion. Leaflets are unequal in size and there is marked marginal chlorosis of the distorted leaves. Very mild strains of the virus may cause only small chlorotic sectors and, occasionally, unequal size of leaflets. On varieties less susceptible than Marshall, symptoms may be so mild that indexing is required for diagnosis,

On Fragaria vesca: On plants of Frazier's U C 1 clone or on Alpine seedlings, symptoms appear about 4 weeks after graft inoculation. On plants of the East Malling clone, symptoms are much slower to develop,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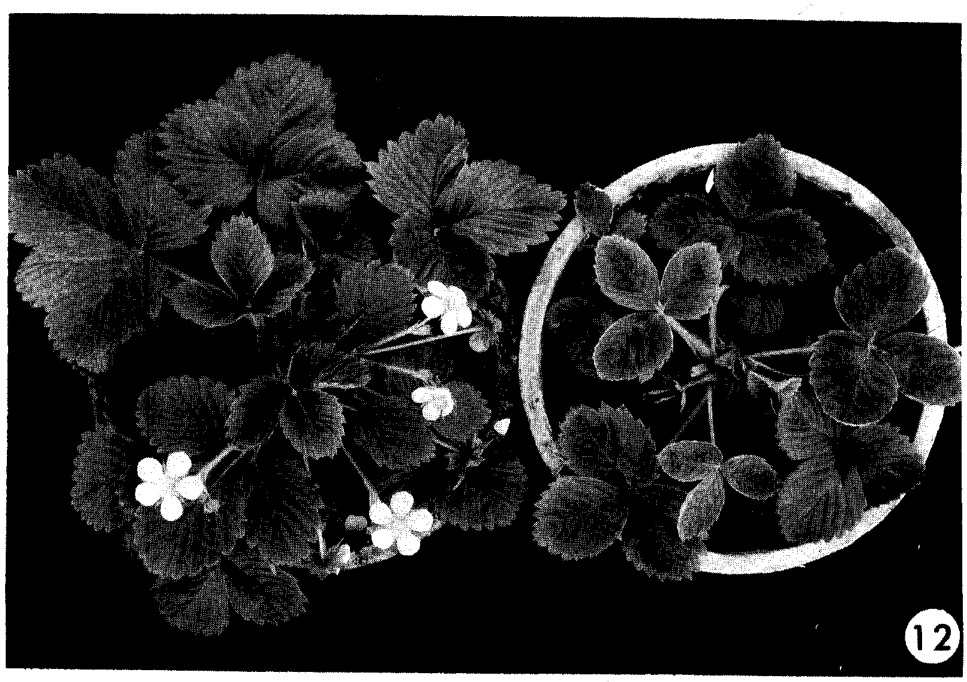
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presumably because the latent-A virus affords partial protection against infection by the crinkle virus. Symptoms are similar on the 3 indicators. Pinpoint chlorotic spots appear which may, in severe cases, cause leaf distortion. Lesions frequently appear on petioles and stolons, sometimes causing,the angular bending shown in Fig. 15. Very mild strains may cause only petiole lesions and, occasionally, the backward bending of a center leaflet.

COMPLEXES WITH OTHER VIRUSES:

Crinkle and mottle viruses together seriously reduce the vigor of plants of the Marshall variety; crinkle, mottle, and mild yellow edge together cause very severe degeneration; and if latent-A is also present the degeneration is even more extreme. These latter complexes will even reduce the vigor and fruitfulness of varieties such as Northwest, which are highly tolerant of the mottle-mild yellow edge complex, and will cause speckling and mild chlorosis.

TRANSMISSION:

The virus-vector relationships of the crinkle virus and its strain are not clearly understood. Vaughan (31), and Prentice (26) report transmission of crinkle by the strawberry aphid without any particular difficulty. More recent attempts by Frazier and Posnette in England (9), and Mellor and Forbes in British Columbia (19), have met with indifferent success or downright failure. Naturally infective aphids, taken from diseased plants in the field, transmitted the virus (9), but no transmissions were obtained by aphids reared in the laboratory and used in controlled experiments.

The most that can be said at the present time is that the strawberry aphids, Pentatrichopus fragaefolii certainly, and probably P. thomasi also, are the principal vectors. According to Prentice and—Woollcombe (29) the aphids can acquire the virus within 24 hours, but an incubation period of 12 to 16 days is required before they can transmit. The insects retain their ability to transmit for several days.

HEAT INACTIVATION:

Posnette and Cropley (22) report elimination of crinkle virus by treatments at 37°C (98.5°F) for 50 days. They found some strains easier to inactivate than others. Posnette and Jha (24) developed crinkle-free plants from stem cuttings taken after 2 or 3 weeks heat treatment of the parent plant. We have developed a crinkle-free plant from an axillary bud excised from an infected plant after 8-weeks heat treatment. The parent plant, however, remained infected.

DETECTION AND IDENTIFICATION:

On commercial varieties crinkle symptoms may be confused with other disorders. For example, the complex of veinbanding and latent-A viruses, or infestations of the shallot aphid (Myzus ascalonicus) or of two-spotted mite, produce symptoms that may be confused with crinkle. However, if the symptoms are caused by the veinbanding-latent-A complex, and no crinkle is involved, grafting to F. vesca will give the distinctive symptoms of this complex (see veinbanding virus). If the trouble is from the shallot aphid, close examination early in the season will reveal the aphids, and the plants will recover completely as new leaves are formed during the summer. If symptoms are due to mite infestation, closer examination will reveal the mites, and leaves formed after elimination of the mites will be normal.

On F. vesca the leaf symptoms of crinkle virus are nearly indistinguishable from those caused by some strains of mottle virus on East Malling F. vesca. This was the source of much of the early confusion between so-called "mild crinkle" (i.e. mottle) and bona fide crinkle. Mottle, however, does not cause the petiole and stolon lesions.

REFERENCES: 9, 19, 22, 24, 26, 29, 31, 33.

ILLUSTRATIONS:

Fig. 13, Marshall with severe crinkle.

Fig. 14. Frazier's U C 1 with crinkle, showing leaf symptoms and petiole lesions.

Fig. 15. Frazier's U C 1 with crinkle, showing lesions which cause sharp bending of the stolon.

LATENT-C VIRUS, McGrew (16)

SYNONYMS: The complex of latent-C and latent-A viruses in East Malling Fragaria vesca was described by Demaree and Marcus (3) as "type 2 symptoms".

GEOGRAPHIC DISTRIBUTION: Eastern North America.

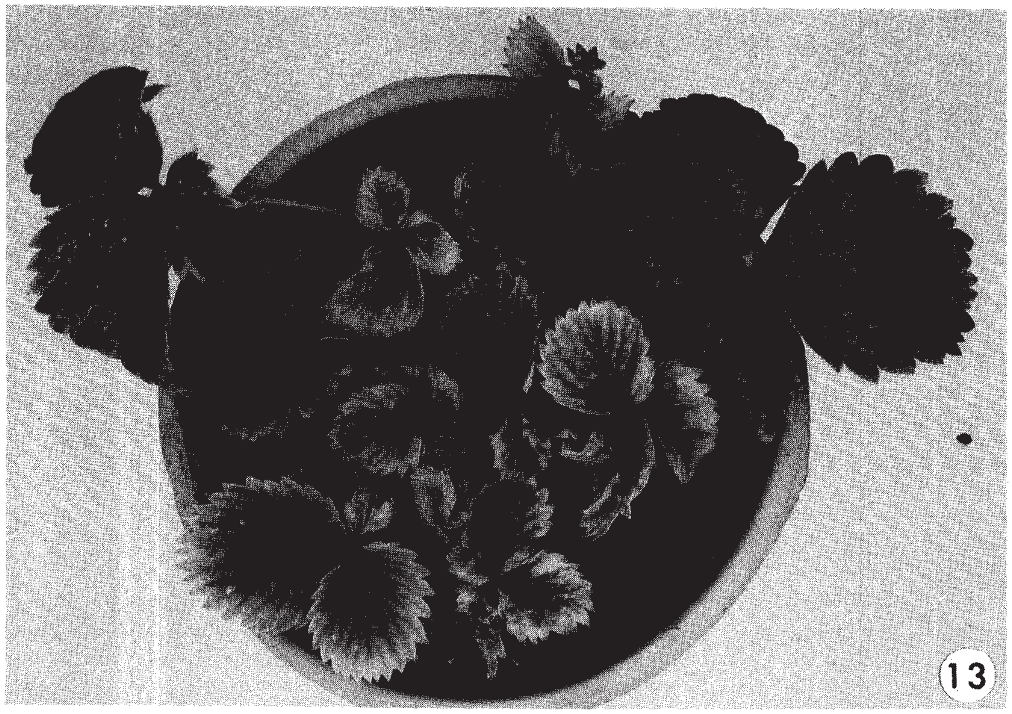
SYMPTOMS: On commercial varieties latent-C virus causes no symptoms, but it decreases vigor of at least some varieties.

On Fragaria vesca of the East Malling clone, Fulton's latent-free clone, and on some seedlings of the East Malling clone, latent-C causes a shock symptom consisting of severe epinasty of the young leaves. This is followed by a proliferation of crowns with very small leaves. On Alpine F. vesca, Frazier's U C 1 clone, Miller's latent-free clone, and on some seedlings of the East Malling clone, latent-C causes no symptoms, but it decreases vigor.

TRANSMISSION is by graft only; no vector has been reported.

HEAT INACTIVATION:

All attempts to free plants of this virus by heat therapy have so far failed.



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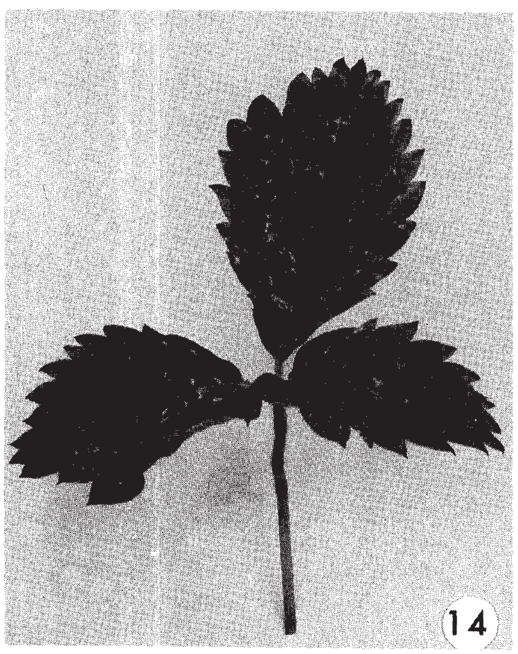

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DETECTION AND IDENTIFICATION:

After mottle has been eliminated by heat therapy, latent-C can be detected by graft-inoculation of East Malling F. vesca. On this indicator latent-C symptoms could only be confused with those of a complex of witches' broom and veinbanding. However the witches' broom virus, with or without veinbanding, causes crown proliferation on commercial Varieties and on all the common indicator species, while latent-C does not cause crown proliferation on commercial varieties, on Alpine, on Miller's latent-free clone, or on Frazier's U C 1.

REFERENCES: 3, 16, 17.

ILLUSTRATIONS:

Fig. 16. Primary symptoms of latent-C in East Malling F. vesca.
Fig. 17. Chronic symptoms of latent-C in East Malling F. vesca.

WITCHES' BROOM VIRUS, Zeller (32)

SYNONYMS: Strawberry virus 2, J. Johnson
Fragaria virus 3, Zeller
Blastogenus fragariae, McKinney
Nanus fragaria, Holmes

GEOGRAPHIC DISTRIBUTION: North America

SYMPTOMS: *On* commercial varieties: Plants are dwarfed, "bushy" in appearance, with multibranched crowns, and erect, spindly petioles supporting small leaves,

On Fragaria vesca symptoms are similar to those on the commercial varieties.

TRANSMISSION:

Zeller (32) reported transmission by the strawberry aphid, Pentatrichopus sp. Mellor and Forbes (19) have been unable to obtain transmission with either P. fragaefolii or P. thomasi.

HEAT INACTIVATION:

We have eliminated this virus from a few plants of the British Sovereign variety by growing them at 95-115" F for 8 or 10 weeks.

DETECTION AND IDENTIFICATION:

On commercial varieties the field symptoms are distinctive and there is usually no difficulty in identifying the disease.

On F. vesca the symptoms are similar to chronic symptoms of latent-C virus. However, latent-C does not produce witches' broom in commercial varieties. Since, in experiments with Premier known to be carrying latent-C, there was no protection against witches' broom, it must be assumed that the two viruses are not related.

REFERENCES: 19, 20, 32.

ILLUSTRATIONS:
Fig. 18. Witches' broom in British Sovereign
Fig. 19, Witches' broom in East Malling *F. vesca*

ASTER YELLOWS VIRUS, Kunkel

SYNONYMS: Western aster yellows virus
Callistephus virus 1A Smith
Chlorogenus callistephi var. *californicus*, Holmes.

GEOGRAPHIC DISTRIBUTION: California, Arkansas.

SYMPTOMS: Phyllody of the flowers of infected strawberry plants is similar to the symptom typical of this virus on other plants. Plants eventually die.

TRANSMISSION is by leafhoppers (*Macrosteles fascifrons*, *Colladonus geminatus*, and *C. montanus*) but with considerable difficulty.

HEAT INACTIVATION: No information.

DETECTION AND IDENTIFICATION: See symptoms.

REFERENCES: 9, 10, 12.

GREEN PETAL VIRUS, Posnette (21)

SYNONYMS: None. Frazier and Posnette (8) state that variations in symptoms on strawberry plants suggest that two diseases may be grouped under the name "green petal." They distinguish these as (a) green petal caused by the virus inducing phyllody in clover, and (b) bronze leaf wilt caused by the clover witches' broom virus. They also suggest that green petal virus may be related to aster yellows virus.

GEOGRAPHIC DISTRIBUTION: England, Eastern Canada.

SYMPTOMS: The flower symptoms are the most characteristic of this disease, and these may appear while the foliage still remains normal. Sepals are enlarged; petals dwarfed and pale green, Some flowers are sterile; others form a small, hard, green receptacle which fails to ripen and from which the achenes stand out, appearing unusually large. Dried inflorescences are a useful symptom in field diagnosis.

Leaves formed' after infection are dwarfed, slightly cupped, with main veins and margins yellow, The old leaves first turn dull yellowish or olive green and then bright red in August and September. The whole plant may collapse and die in mid-summer or there may be temporary recovery in

September with the formation of secondary crowns with minute leaves. The stolons are short and thickened, and the young runner plants extremely dwarfed.

TRANSMISSION is by graft; not by the strawberry aphid. The virus has been transmitted from strawberry to clover by leafhoppers.

HEAT INACTIVATION: No information.

DETECTION AND IDENTIFICATION: See symptoms.

REFERENCES: 2, 8, 9, 13, 21.

ILLUSTRATIONS:

Fig. 20. Flower symptoms of green petal virus in contrast to normal flowers, on field plants of the variety Senator Dunlap.

Fig. 21. Flower symptoms of green petal virus.

Fig. 22, Fruit symptoms of green petal virus.


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CHARACTERISTICS OF STRAWBERRY VIRUSES

Virus	Symptoms: Commercial varieties	F. vesca clones: EMC	Alpine	UC 1	EMK	Vectors	Inactivation by heat
Mottle	-	*S*	S	*S*	*S*	aphids NP	A
Latent-A	-	-	-	-	-	unknown	B
Veinbanding	-	S	*S*	S	S	aphids NP	C
Mild yellow edge	-	S	*S*	*S*	S	aphids P	C
Crinkle	S	S	*S*	*S*		aphids P	B
Latent-C	-	S	-	-	S	unknown	D
Witches' broom	S	S	S	*S*	S	aphids ?	B
Aster yellows	S					leafhoppers	
Green petal	S					leafhoppers	

Key to Symbols

Symptoms: *S* indicates diagnostic symptoms; - indicates no diagnostic symptoms

Vectors: NP non-persistent in vector; P persistent in vector

Inactivation by heat: A readily inactivated.
B inactivated only by prolonged heat treatment, or by taking cuttings from heat treated plants.
C inactivation in a single instance,
D ,has not yet been inactivated.

Summary

The detection and identification of latent viruses in commercial strawberry plants usually requires three steps: preliminary indexing to determine whether the mottle viruses are present, heat treatment to eliminate mottle, and re-indexing the heat-treated plants to detect any heat-stable viruses. For the re-indexing, three indicators are desirable:' East Malling F. vesca to show veinbanding or latent-C (or mottle), U C 1 or Alpine to show mild yellow edge, and one of the latent-free F. vesca clones infected with veinbanding, to show latent-A. When the results of indexing are negative the 'tests should be repeated several times before any plant is pronounced virus-free.

Acknowledgements

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