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THE CHEMICAL CONTROL OF BLACK CURRANT REVERSION VIRUS AND ITS GALL MITE VECTOR (*PHYTOPTUS RIBIS* NAL.*): A REVIEW OF THE LITERATURE

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Abstract

The numerous experiments on the chemical control of black currant gall mite (*Phytoptus ribis* Nal.) are considered in relation to current recommendations. All the available materials have limitations: lime-sulphur and sulphur may be phytotoxic; endrin and endosulfan cause undesirable residues on the fruit.

Experimental designs are discussed, particularly those for supplementing the meagre data on the incidence of reversion virus after controlling the mite vector.

Black currant reversion virus, transmitted by the gall mite *Phytoptus ribis* Nal., causes the most important disease affecting the crop in Britain and some other European countries. The numerous experiments on the chemical control of mites are considered in the present paper, together with the meagre information on the effects of chemicals on the spread of virus.

Life history of black currant gall mite in relation to control measures

The black currant (*Ribes nigrum* L.) is the usual host of *P. ribis*, which can infest the buds of all the main commercial varieties. Infested buds fail to differentiate flowers or leaves and become rounded galls, each containing up to 35,000 mites (10). Growth and reproduction within galls is checked only for a short period during the winter and when mites disperse to vulnerable buds of new growth.

The most satisfactory chemical control of mites would be obtained by a translocated material that is active against mites in galls following winter applications to dormant bushes. This approach has been attempted unsuccessfully by Collingwood, Vernon and Legowski (12), and Smith (31), who suggested that there was only limited movement of solutes within dormant bushes and that during the summer the main flow was towards growing points and not into galls. Chemicals applied during the dispersal period have been much more effective and have been used as routine control measures for many years.

The onset and duration of mite dispersal vary with season and are influenced by climatic factors that determine the growth of bushes and the activity of mites (32). Usually the galls swell and open slightly in March or April as normal growth starts. In warm conditions mites then congregate on the surface before dispersing to new growth. Some mites emerge before blossoming begins, but this is unimportant because vulnerable buds are then virtually inaccessible. Peak dispersal occurs during flowering, when vegetative growth is rapid and many buds are accessible to mites. The peak may be sudden and intense or build up gradually, according to weather. Relatively little dispersal occurs after blossom, except in sheltered localities or when previous conditions have been unfavourable.

Some mites walk or leap from galls and others are carried by wind, rain or insects, of which aphids seem to be the most important (24). The relative importance of the different methods of dispersal has not been evaluated and probably depends upon season and environment. The process is extremely hazardous and wasteful and relatively few mites become established in new buds (39). Some mites die because they fail to leave galls or do not reach black currant plants. Other mites fail to enter the meristematic apices, which seem to be the only sites for feeding and reproduction. There are numerous natural hazards and ample opportunities for killing dispersing mites by chemicals. However, effectiveness is limited by the difficulty of maintaining an adequate toxic deposit as the shoots and foliage develop rapidly throughout the prolonged period of dispersal.

* Referred to as *Eriophyes ribis* (West.) Nal. in early publications and now sometimes considered to be *Cecidophyopsis ribis* (West.).

Chemical control of black currant gall mite

Sulphur and lime-sulphur

The effectiveness of sulphur and lime-sulphur against spider mites stimulated early experiments with these materials against the black currant gall mite (7). It was slow, inconvenient, and uneconomic to spray bushes repeatedly using the machines then available. Consequently, single concentrated sprays were applied before blossom, to avoid the phytotoxicity caused by later applications. Lime-sulphur at 8·3% was more effective against mites than at 6·2% when used as the first leaves 'were about the size of a sixpence', and control was not improved by an additional post-blossom spray. Later work demonstrated the advantage of delaying the 8·3% spray until the late grape stage, when the flowers had appeared but not opened (15, 23). A standard concentration of 5% lime-sulphur was eventually recommended; 2% for varieties sensitive to sulphur (25). Later, concentrations of 1% were used on slightly affected bushes, or after stronger sprays had been used for some years (16).

Single applications of lime-sulphur at grape stage have the great disadvantage that they fail to reach and protect the extensive amount of vulnerable foliage developing during the blossom period. Moreover, it is unlikely that the deposit on the galls and old wood persists for more than a limited part of the dispersal period (30). Additional sprays at lower concentration to decrease the risk of phytotoxicity are desirable and became practicable following the introduction of mobile spray machinery during and after the second world war.

Invariably, the effectiveness of single pre-blossom applications was increased by additional sprays during flowering (31), although infestations were not eradicated even after ten applications of 2% lime-sulphur without wetter (1), and sulphur and lime-sulphur were inferior to endrin (11, 12).

Formerly, sulphur materials were usually applied without wetter, which was considered to be unnecessary or disadvantageous because of increased run-off. The effectiveness of lime-sulphur against mites is now known to be much greater when used with a wetter (27, 31, 32, 34). Dioctyl sodium sulphosuccinate has been recommended, although non-ionic wetting agents are likely to be equally effective and may be preferable.

Small volume and neat applications of lime-sulphur have generally given unsatisfactory results (11, 18, 27). Suggestions that wettable or colloidal sulphur preparations provide effective and less phytotoxic alternatives to lime-sulphur (19, 28, 31, 32) have yet to be confirmed. Indeed, in one trial growth was suppressed more by colloidal sulphur than by lime-sulphur (41).

Chlorinated hydrocarbons

Endrin is the most effective material yet found against mites. It gave excellent control when used in Norway before and after flowering (36), and in England it was outstanding of the numerous materials tested (11). Consistently good results were obtained in experimental plots when 0·04% endrin with wetter was applied thoroughly and at large volume; indeed, single applications were effective at the end of blossom. Results in commercial farms were less satisfactory, indicating the necessity for thorough spraying even with so effective a material.

The first promising result with endosulfan (11) was confirmed in most later experiments (6, 11). Applications at 0·05% with wetter at the beginning and end of flowering greatly decreased heavy infestations, particularly when made by hand-lance (5). Five sprays were much more effective than lime-sulphur or colloidal sulphur, and only slightly less effective than endrin in protecting bushes from infestation (40, 41).

Other materials

The systemic insecticide fluoroacetamide is unique in eradicating mites from dormant shoots dipped before propagation (8). Moreover, sprays applied during and after blossom kill mites already established in new buds. Pre-blossom applications are ineffective, presumably because fluoroacetamide is very water-soluble and not persistent (11, 12).

Numerous other materials have been tried unsuccessfully against black currant gall mite, including some that are highly effective against other eriophyids (11).

Phytotoxicity and residues

Black currants usually begin to grow and flower in April, when they are very sensitive to weather and sprays that may damage leaves and decrease fruit set and yield. A wetting agent alone may decrease viability of pollen and the chances of pollination (2), and damage may be increased by adding acaricides. There is also the risk of killing bees or other beneficial insects visiting the crop, and of leaving undesirable residues on the fruit.

Lime-sulphur

Sulphur or lime-sulphur sprays almost invariably cause discoloration of the leaves, possibly followed by necrosis, abscission, decreased vegetative growth and crop. Unfortunately, the evidence on phytotoxicity is limited because the numerous observations on leaf damage have seldom been followed by growth and crop records in controlled experiments.

Severe damage was recorded in east and south-east England (15, 20, 23), particularly on the variety Goliath, and in seasons when cold winds from the north-east were accompanied by night frosts (16). Recently at East Malling, single large-volume applications of 2% or 8% lime-sulphur, without wetter, at grape stage or later, damaged leaves but not crop (11, 17). By comparison, four applications of 1% lime-sulphur without wetter in each of the seasons 1961-63 had a deleterious effect on shoot growth and crop that was cumulative and varied with variety and season (18).

At Long Ashton, large-volume applications of 1% lime-sulphur with wetter damaged leaves without affecting growth or crop until 1963 (34). The damaged bushes partially recovered by late growth made in July and August, when the unsprayed controls were severely damaged by the leaf-spot fungus (*Pseudopeziza ribis* Kleb.).

General experience is that the phytotoxicity of lime-sulphur depends upon concentration, method, time and year of application, as well as on the size, variety, and vigour of the sprayed bushes. Damage is unpredictable and this limits the commercial use of lime-sulphur, although it is relatively non-toxic and may partially control mildew and leaf spot without adversely affecting beneficial insects (35).

An undesirable taint was detected on canning fruit from bushes that had received more than three sprays of 1% lime-sulphur (4), but this is unimportant since much fruit is made into juice by a process involving sulphur dioxide.

Chlorinated hydrocarbons

Leaves are not damaged by applications of endrin or endosulfan at recommended rates. Moreover, there is no evidence that they decrease crop directly or indirectly by killing bees or other beneficial insects (5, 6, 9, 12, 13). Residues on the fruit at harvest present a greater problem; both endrin and endosulfan persist for months after spraying and the concentration, timing and frequency of applications are restricted legally to prevent concentrations exceeding a low-tolerance (11, 12).

Fluoroacetamide

The use of fluoroacetamide was restricted originally because chlorosis of the young leaves and decreased crop were reported in one of the initial experiments (12). Cuttings (8), fruiting bushes (13), and non-fruiting bushes (41) were damaged in later experiments. Fluoroacetamide was eventually withdrawn from use in agriculture because of toxic hazards.

Spray programmes

All materials available for controlling gall mite have limitations, and spray programmes compromise between the frequent applications that are required for effective control of virus and vector, and the risks of phytotoxic or dangerous residues. Recommendations differ according to circumstances and the material applied.

Nursery and non-fruiting bushes

Nursery bushes and plantations that have been pruned to ground level do not crop, and endrin can be used without restriction. Originally, applications of 0·04% were recommended in mid-April and a month later. However, it is preferable to begin spraying when shoots start to grow rapidly, usually the week after neighbouring bushes begin to flower. Four additional sprays should be applied at intervals of 10-14 days.

Endosulfan at 0·05% is a somewhat less toxic and less effective alternative to endrin, for growers who prefer not to use such a persistent and dangerous material. Lime-sulphur at 1% and equivalent sulphur preparations are relatively harmless to use, but five applications may not be entirely effective against mites and are likely to suppress the growth of sensitive varieties. Furthermore, leaf damage may invalidate the diagnosis of certain virus diseases (42).

Fruiting bushes

Current recommendations (33) are that lime-sulphur should be used as flowering begins, when the first flowers open, and two weeks later. For severely infested bushes the first spray should be followed by three fortnightly sprays, omitting the wetter at full blossom.

Phytotoxicity can be avoided by using endosulfan, but only two applications are allowed and these are usually applied as flowering begins and three weeks later, to avoid killing beneficial insects that are active during blossom (5, 6). Protection can be supplemented by intermediate and post-blossom sprays of lime-sulphur, although the effectiveness of such mixed schedules has received little attention.

The effectiveness of endrin against mites cannot be fully exploited on fruiting bushes. Officially, only one application of 0·04% at grape stage is allowed and this may be used instead of lime-sulphur or endosulfan as flowering begins. Even this application is banned by certain processors.

The way in which different materials affect mites

Conventional sprays applied during dispersal may kill mites in or on galls. Alternatively, mites may be killed on young shoots or in developing buds. The mortality at each site has never been evaluated ; it is likely to depend upon spray material and method, and upon the number of mites spreading between sprayed bushes compared with spread from outside sources.

Lime-sulphur

When lime-sulphur is sprayed onto galls, it forms a deposit toxic to mites (16, 21) ; it also forms a toxic vapour (21, 35) considered to be sulphur and not hydrogen sulphide or sulphur dioxide (14). Mites inside the galls and young buds are unaffected by lime-sulphur sprays (11, 16) and toxicity must be due solely to the superficial deposit on the galls and foliage. Pre-blossom sprays applied as dispersal commences can be effective only against mites on galls. Later sprays will also protect the developing foliage, whereas post-blossom sprays at the end of dispersal are virtually ineffective (16, 20, 32, 34).

Painting the galls and old wood of potted bushes with lime-sulphur before dispersal occurred was less effective in preventing further infestation than painting the new growth, or merely dropping lime-sulphur into the leaf axils as they appeared (32). By comparison, Jary *et al.* (16) considered the protection of young foliage to be less important than the effect on mites on galls. Their suggestion was supported by the limited ability of lime-sulphur or colloidal sulphur sprays to protect bushes from infestation by mites spreading from unsprayed sources (40, 41). The inferiority of the sulphur materials compared with endrin was then greater than in experiments in which galls were sprayed (34).

Endrin

Endrin decreased the number of mites invading the new buds of sprayed bushes (11, 12). Mites could have been killed in or on the overwintering galls or on the new foliage. However, experiments on the spread of virus from unsprayed sources suggested that the young foliage was protected even less effectively than by colloidal sulphur or lime-sulphur (40, 41). The effectiveness of endrin against mites was attributed, therefore, to the eradication of mites from recently invaded buds (11, 12). The ability to eradicate mites from buds also explains why endrin differs from lime-sulphur in that post-blossom sprays are more effective than pre-blossom. Indeed, the most effective single spray of endrin is when the dispersal of mites is virtually complete. The effectiveness of endrin against mites in galls has not been established and it has been found only recently that endrin and endosulfan release a toxic vapour that affects mites less rapidly than gaseous sulphur (35). This observation warrants further study on the behaviour and toxicity of spray deposits.

Other materials

It is not known how sulphur, endosulfan, or fluoroacetamide affect mites, although wettable sulphur is likely to behave like lime-sulphur. Endosulfan and fluoroacetamide resemble endrin in killing mites inside recently invaded buds (11), and in their inability to protect bushes from virus infection (40, 41).

Future investigations

Further information on the persistence, volatility and activity of spray materials is essential for a full interpretation of the results of experiments on the chemical control of mites and reversion virus. Much more attention should be given to this problem so that spray materials and methods can be selected on a rational basis, and so that residue data from chemical analyses can be utilized effectively. There is now no clear evidence on the performance required of spraying machinery, nor on the precise target to be reached by each type of spray. Experiments in which only changes in the number of galls are recorded are clearly inadequate. Much additional information can be obtained by detailed observations on the dispersal of mites from galls and their entry into the buds of sprayed and unsprayed bushes. Bushes infected with reversion virus are particularly suitable for such experiments, as their buds are highly vulnerable to mites (37, 39).

Chemical control of black currant reversion virus

The control of reversion virus by chemicals has received little attention and the incidence of virus has usually been ignored in attempting to control the mite vector. This limits the interpretation and practical relevance of the results obtained, because experience with other crops is that the spread of virus is not always checked by controlling the vector (3). Moreover, mites are important primarily as vectors of reversion virus. The direct damage they cause is probably insignificant unless bushes are already invaded systematically by reversion virus, of which the most virulent strains cause bushes to become virtually sterile (38).

Healthy bushes have considerable natural resistance to infestation by mites, but this is broken down following infection with reversion virus (37, 39). Consequently, failure to standardize or record the health of bushes in experiments on the control of mites greatly increases variability, because mites are relatively easy to control on healthy bushes (15).

The virus-infected bushes first recorded in one early experiment with lime-sulphur (15) were attributed to the use of contaminated stock. Subsequent infections were much more numerous in the unsprayed plots than in those receiving lime-sulphur. Similar experiences have been reported elsewhere (22, 29). In the most recent experiments (40, 41) effectiveness of sprays against mites was not correlated with ability to protect bushes from infection with virus. Colloidal sulphur and lime-sulphur were the least effective materials against mites, yet both decreased the incidence of virus. Endosulfan and fluoroacetamide prevented the establishment of mites, yet did not affect virus spread. Endrin decreased virus spread only when used ten times at weekly intervals in 1962 and when used five times at intervals of ten days in 1963.

Experimental design

Bushes in plantations

Some spraying experiments have been done on fruiting bushes in plantations at conventional wide spacings. Sprays have been applied by machines available commercially, and the results have been of immediate value in evolving routine spray programmes. Such experiments have disadvantages and limitations, as large plots and extensive guarding are necessary to prevent spray drift. It is also difficult to obtain sufficiently large plantations with a heavy and uniform distribution of galls and reverted bushes. Diseased plantations are usually intolerable at research and experimental stations ; experiments in commercial plantations are difficult to control and supervise and may be exposed to contamination.

When suitable plantations are available, precision may be improved by using pre-treatment records of the incidence of galls and reversion. If bushes are not subsequently pruned or removed, post-treatment observations can then be amended by covariance analysis or expressed in relation to pre-treatment records.

Bushes in small plots

As an alternative to using plantations, some recent experiments have been done in small areas closely planted with bushes that were heavily infested with galls and presumably infected with reversion virus. Galls were often so numerous that it was impracticable to count them on entire bushes and estimates were made of the number per unit length of shoot (11). Alternatively, mites were counted in macerates of buds (12).

Such small experiments have the advantage that they may be isolated, and a sequence of experiments can be done on the same bushes if sprays are omitted for one or two years between experiments to allow a uniform infestation to become re-established. In this way large numbers of chemicals were tested against mites (11), but it was impossible to compare commercial methods of application as large or very powerful spray machines could not be used in such small plots. Interference between plots was also a disadvantage, and the experiments provided no information on the spread of virus. Furthermore, the heavy infestations of mites on the reverted bushes provided too stringent a test of the spray materials, and biassed the results in favour of materials that eradicated mites in buds. Such heavy infestations are unlikely to develop within plantations if reverted bushes are diagnosed and removed promptly. The problem then is to protect healthy bushes from mites and reversion spreading from elsewhere.

Assessing virus spread

Special problems are raised in comparing the effects of chemicals on the spread of reversion virus, which can be determined much less readily than the spread of mites. One difficulty is that virus symptoms do not appear until the year after infestation with mites. Symptoms are then difficult to see and easily missed because at first they are restricted to a few slightly affected shoots. Consequently, experiments should run for three years to ensure correct diagnosis. Significant differences in virus incidence can be determined only by larger plots or greater replication than is required for analyses of galls.

In the only detailed experiments (40, 41), plots of healthy bushes receiving different spray treatments were exposed in a Latin square or randomized block design to mites spreading from unsprayed sources of virus. The experiments simulated in an extreme form the situation in commercial nurseries and fruiting plantations, where bushes are exposed to spread from outside sources. The experimental design was inappropriate for assessing spread between sprayed bushes, which occurs commonly in nurseries and plantations. This situation can be simulated only by much more complex designs with sprayed sources within plots, and guard rows to prevent cross-contamination. Such an approach has not been made, and there may be difficulties if spraying the sources of virus decreases spread to such an extent that it can be assessed accurately only by using very large plots or numerous replicates to permit valid comparisons between treatments.

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