Green crinkle disease of apple

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(Received 4 March 1974)

ABSTRACT

Apple green crinkle has been recorded on 22 cultivars in New Zealand, and it is common in all apple growing districts. Generally symptoms are confined to the fruit, but in two cultivars tree growth is affected. Symptom expression varies widely between seasons, and tends to be most pronounced on weak trees.

Under test conditions green crinkle was found to reduce size but not number of ‘Dunn’s Favourite’ fruits, while in ‘Lord Wolseley’ both size and number of fruits were reduced. There appear to be several strains of green crinkle capable of producing symptoms of varying severity. No evidence of field spread has been reported except in one case where root grafting probably occurred.

Green crinkle has been eliminated from nucleus lines of all important apple cultivars by either selection or heat treatment combined with tip grafting. Healthy material has been made available to all nurserymen.

INTRODUCTION

A malformation of apple (Malus syvrestis (L.) Mill.) fruits known originally in Canada under the name of false sting (Hockey 1941) and later described in New Zealand as green crinkle (Atkinson 1946) has been regarded as a virus disease since Hockey (1941) reported the condition to be graft transmissible. It is now considered that several apple diseases once thought to be caused by viruses, including apple chat fruit, apple rubbery wood (Beakbane et al. 1971), and apple proliferation (Giannotti et al. 1968), are caused by mycoplasma, and there are some indications that green crinkle could fall into the same category.

Green crinkle appears to have been first observed in Canada and New Zealand during 1934 (Hockey 1941; Atkinson & Robbins 1951), and what was probably the same disease was described from Tasmania in 1937 (Carne & Martin 1937). Since then diseases similar to if not identical with green crinkle have been reported from most major apple-growing countries including England (Wallace et al. 1944), Norway (Ramsfjell 1950), Denmark (Wagn et al. 1955), Australia (Anonymous 1956), France (Morvan 1958), United States of America (Thomas 1961), Japan (Sawamura 1965), and Poland (Zawadzka et al. 1967). A study of the literature suggests that this disease is more widespread, of greater incidence, and infects a wider range of cultivars in New Zealand than in other countries. However, high incidence of the disease in the cultivar ‘Granny Smith’ has been reported from Tasmania (Johnstone & Martin 1968). Difficulty in locating trees of the popular ‘Granny Smith’ cultivar free of green crinkle to provide budwood for commercial production of nursery trees has made the disease particularly important in New Zealand.

In the present paper some additional symptoms of apple green crinkle are described, further information on cultivar range and incidence is given, field spread is discussed, and steps being taken to control the disease are outlined.

SYMPTOMS

The most characteristic symptoms of apple green crinkle as described by Hockey (1941, 1943) in Canada, Atkinson (1946) and Atkinson & Robbins (1951) in New Zealand, and Pares & Hutton (1961) in Australia, as well as a number of workers in other countries, are as follows:

Symptoms first appear on fruits when they are 1 to 2 cm in diameter as small creases on the surface. Owing to uneven growth these fruits become much distorted as the season advances (Fig. 1). Irregular areas of russet frequently develop in the folds accompanied in some cultivars such as ‘Gravenstein’ by pronounced cracking (Fig. 2). When a number of depressions form on one fruit it usually remains stunted, but when only a single depression develops fruit size may not be markedly restricted.

N.Z. Journal of Agricultural Research 17: 137-46
Fig. 1 — Symptoms of green crinkle on fruit of 'Granny Smith' apples (× 1.8).
[Photo: L. H. Wright]

Fig. 2 — Distortion, russetting, and cracking on 'Gravenstein' fruits caused by green crinkle (same size).
[Photo: L. H. Wright]
Less commonly, infected fruits may show a number of wart-like swellings some of which may be covered with rough russet (Fig. 3). These two symptoms may occur on separate trees, on the same branch, or even together on the same apple. Below the depressions or swellings the vascular system is distorted and green. This colouration may extend to the core zone, but is most pronounced immediately below the epidermis. It is not uncommon for symptoms to remain confined to one branch of a tree for many years. Also symptoms fluctuate from season to season and can be present one year and absent the next.

It has been a generally recognised characteristic of apple green crinkle that symptoms are confined to the fruits, but Ramsfjell (1957) stated that growth of trees was often retarded, and Atkinson (1971) reported that in one cultivar the disease can cause a marked delay in foliation.

**Transmission of apple green crinkle and its effect on tree growth and on fruit size and yield**

During the 1950s high incidence of a fruit-distorting condition in the cultivar 'Lord Wolseley' caused considerable concern among orchardists in mid-Canterbury. Although the condition was diagnosed as apple green crinkle, symptoms were somewhat different from those usually encountered on most other cultivars. The fruits showed more russet and less distortion than normal (Fig. 4).

To determine whether the variation in symptoms was due to cultivar reaction or strain difference, a transmission trial was initiated in 1961 using as sources of inoculum a 'Lord Wolseley' tree showing symptoms typical of that cultivar and a 'Dunn's Favourite' tree with the more usual green crinkle symptoms. Healthy 'Northern Spy' rootstocks were budded with healthy or infected 'Lord Wolseley', healthy 'Dunn's Favourite', or double budded with healthy and infected 'Dunn's Favourite' or healthy 'Lord Wolseley' and infected 'Dunn's Favourite'. On the double-worked trees the healthy scion was placed uppermost and both scions were allowed to develop. The number of trees budded is shown in Table 1. All trees were lined out at 1.8 m spacing during the winter of 1962. The trial was maintained until 1969, but during the last two seasons only general observations were made.

**RESULTS**

*(a) Transmission*

The transmission results are shown in Table 1. Results in Table 1 show that green crinkle was transmitted from diseased buds to all originally healthy scions, but that the strain from 'Dunn's Favourite' induced earlier development of symptoms than did the 'Lord Wolseley' strain. This suggests that 'Dunn's Favourite' carried the more severe strain, and this was borne out by the severity of
TABLE 1 — Transmission of green crinkle from infected ‘Dunn’s Favourite’ and ‘Lord Wolseley’ to healthy ‘Dunn’s Favourite’

<table>
<thead>
<tr>
<th>Cultivar and health status†</th>
<th>No. trees</th>
<th>No. trees showing fruit symptoms/No. trees bearing fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy ‘Dunn’s Favourite’</td>
<td>6</td>
<td>0/2</td>
</tr>
<tr>
<td>Healthy ‘Lord Wolseley’</td>
<td>4</td>
<td>0/4</td>
</tr>
<tr>
<td>Infected ‘Lord Wolseley’</td>
<td>5</td>
<td>1/5</td>
</tr>
<tr>
<td>Healthy ‘Dunn’s Favourite’</td>
<td></td>
<td>4/5</td>
</tr>
<tr>
<td>Healthy ‘Dunn’s Favourite’</td>
<td>†</td>
<td>7</td>
</tr>
<tr>
<td>Infected ‘Dunn’s Favourite’</td>
<td></td>
<td>0/2</td>
</tr>
<tr>
<td>Infected ‘Lord Wolseley’</td>
<td>§</td>
<td>0/0</td>
</tr>
</tbody>
</table>

† All trees produced by budding to ‘Northern Spy’ rootstocks in 1961.
‡ The one infected tree which had not shown any symptoms previously developed mild symptoms on a few fruits in 1967 and more pronounced symptoms in the following two years. This could indicate that the tree carried a mild strain which did not produce symptoms until 1967 or that the virus had been transmitted by some vector. However, as it was only 1.8 m away from an adjacent infected tree, it is more likely that it became infected through root grafting, which has previously been found to occasionally take place between closely planted apple trees (Hunter et al. 1958).
§ Double-worked trees on which each scion was recorded separately.
This marked reduction in fruit numbers and yield of 'Dunn’s Favourite' strain on 'Dunn’s Favourite' is difficult to interpret. This strain produced symptoms on only 56 percent of the fruits and did not reduce fruit size. However, the symptoms produced were typical of those normally occurring on 'Dunn’s Favourite'. This suggests that the difference in fruit symptoms on the two varieties is caused by cultivar reaction. The results suggest also that the infected 'Lord Wolseley' carried a milder strain of green crinkle.

Because the infecting 'Lord Wolseley' scions were allowed to remain but did not produce fruit, the influence of the 'Lord Wolseley' strain on 'Dunn’s Favourite' was probably due to the disease on tree growth as recorded under the following section (c).

(c) Effect on tree growth

Infection with green crinkle did not appear to have any effect on bud union on either 'Dunn’s Favourite' or 'Lord Wolseley'. On 'Lord Wolseley', however, it did have an effect on tree growth. Infected trees showed delayed foliation and flowering in the spring (Fig. 5), fewer leaves during the summer, and premature leaf fall in the autumn (Fig. 6). These symptoms did not occur on 'Dunn’s Favourite' infected with either strain, but infected trees were smaller and appeared to be slightly less vigorous than healthy ones.

In field surveys no difference in foliation or vigour could be detected between healthy and infected trees of 'Granny Smith'.
TRANSMISSION EXPERIMENTS

In 1950, at the DSIR Appleby Research Orchard, Nelson, a range of cultivars were grafted to one 'Dunn's Favourite' and one 'Sturmer' tree, both of which carried fruits with a high percentage of apple green crinkle symptoms. The following cultivars were grafted to 'Dunn's Favourite': 'Ballarat', 'Cleopatra', 'Delicious', 'Dougherty', 'Jonathan', 'Kidd’s Orange Red', 'Red Gravenstein', 'Rome Beauty', 'Tasma', and 'Winesap', and the same cultivars except 'Cleopatra' were grafted to the 'Sturmer' tree. Grafts of the different cultivars were randomised through the two trees so that they would have equal chances of contracting infection.

In 1952 symptoms occurred on fruits of 'Cleopatra' and 'Rome Beauty' and in 1953 they appeared on 'Red Gravenstein'. By 1955 no symptoms had developed on fruits of any of the other cultivars, and although the 'Sturmer' tree was observed until 1971, no symptoms were observed on the four surviving grafted cultivars.

Under New Zealand conditions apple green crinkle symptoms are found much less frequently on red-fruited than on green-fruited cultivars. In the spring of 1966 an experiment was initiated to determine whether green crinkle could be transmitted to a range of red cultivars. If transmission did not occur to the red cultivars, it was thought that reworking susceptible cultivars with the non-susceptible cultivars would be a method growers could use to overcome the green crinkle problem in established trees. To each of seven infected 'Dunn's Favourite' trees were grafted six to eight scions from one of the following red-fruited cultivars: 'Hawke's Bay Red Delicious', 'Jonathan', 'Kidd’s Orange Red', 'Red Dougherty', 'Red Jonathan', 'Spartan', and 'Splendour'. In the next year healthy 'Granny Smith' grafts were worked to some scions of each of the red cultivars to ascertain whether any of those which failed to develop symptoms accepted the disease. Fruit was present on some scions of all the red cultivars from 1968 onwards. No symptoms appeared in 1968,
but in 1969 some fruits of both 'Jonathan' and 'Spartan' showed symptoms. The trial was continued until 1971, but symptoms did not develop on any of the other cultivars except 'Splendour', on which symptoms appeared on 7 of 10 fruits produced in the final year of the experiment.

'Granny Smith' scions worked to 'Kidd's Orange Red' did not produce any fruit during the trial, and those on 'Red Jonathan' produced only one fruit and this failed to show symptoms. All fruits produced by the 'Granny Smith' scions on the other five red cultivars developed typical symptoms of apple green crinkle.

Because a number of the varieties which did not develop symptoms in the above trials have been recorded as showing symptoms in the field, it would appear that there are different strains of green crinkle capable of producing symptoms only in certain cultivars. The results also indicate that some cultivars are capable of carrying some strains of green crinkle without showing symptoms.

**Cultivar Host Range**

Symptoms of apple green crinkle have been found on many cultivars both in New Zealand and other countries. In New Zealand, symptoms have been found to occur naturally on the following cultivars: 'Cox's Orange Pippin', 'Dunn’s Favourite', 'Granny Smith*', 'Gravenstein*', 'Northern Spy*', 'Statesman', 'Sturmer Pippin*' (Atkinson 1946), 'Lord Wolseley' (Atkinson & Robbins 1951), 'Scarlet Pearmain' (Chamberlain 1954), 'Ballarat', 'Cleopatra*', 'Delicious*', 'Dougherty', 'Goa Apple' 'Golden Delicious', 'Golden Noble', 'Red Dougherty', 'Red Gravenstein', 'Rome Beauty' (Atkinson *et al.* 1965), 'Democrat', 'Gala', 'Giant Jeniton', 'Splendour', and 'Jonathan' (not previously recorded).
Cultivars marked with an asterisk have been recorded from other countries also as showing symptoms.

**Incidence and Economic Importance**

Although green crinkle has been recorded in most apple growing countries, reports suggest that incidence is comparatively low in countries other than Tasmania and New Zealand. In Tasmania Johnstone & Martin (1968) stated that the disease is serious on 'Granny Smith' and estimated from Extension Officers' reports that of 320,000 trees of this cultivar, 5 to 10 percent were infected.

**Incidence in New Zealand**

Green crinkle has been found on 22 cultivars in this country, but reports from Horticultural Advisory Officers indicate that incidence is usually low except in 'Granny Smith', 'Lord Wolseley', and 'Dunn's Favourite'.

The importance of apple green crinkle as a disease of 'Granny Smith' was recognised when this cultivar was gaining popularity in New Zealand. A survey made by Mr Hogg, an Instructor in Horticulture, in the Mapua area of Nelson during 1946 and reported by Atkinson & Robbins (1951) showed that of 61 blocks surveyed, the disease occurred in 39, and that of the 8420 trees inspected, 6.8 percent were infected. Since then no similar surveys of 'Granny Smith' trees have been carried out, but reports from Extension Officers of the Ministry of Agriculture & Fisheries and observations of the authors suggest that there has been a gradual increase in the incidence of the disease in this cultivar.

Although it is unusual for green crinkle symptoms to occur on all trees in a block, in one planting of 49 'Granny Smith' trees top worked on 'Sturmer' all showed symptoms. In this instance infection was traced to the tree from which scions had been taken.

Because of its high incidence and serious effect on cropping and fruit quality, green crinkle has been of considerable concern to growers of 'Lord Wolseley'. A survey carried out in two blocks during 1959 by Mr J. D. Galletly, Senior Horticultural Inspector of the Department of Agriculture, showed that of 1083 trees 5.5 percent were infected. A further survey carried out by officers of the Department of Agriculture in mid-Canterbury in 1961 showed that of 417 'Lord Wolseley' trees surveyed by officers of the Department of Agriculture in mid-Canterbury, 41 percent of the trees showed symptoms in 1961, 20 percent in 1962, and 26 percent in 1963.

Economic importance in New Zealand

Apple green crinkle is of greatest economic importance on 'Granny Smith', which not only has a high incidence of the disease but is the most extensively grown cultivar. According to the latest official tree survey (Anonymous 1970) there are 297,052 'Granny Smith' trees and this represents more than 20 percent of all apple trees grown in New Zealand. Furthermore, the disease has been of particular concern in this cultivar because of the difficulty in locating propagating material free from infection.

Although incidence of green crinkle is probably highest in 'Lord Wolseley', its overall importance is not great, as in the last survey there were only 4780 trees of the cultivar recorded and its popularity was waning. In 'Dunn's Favourite' too the disease is of comparatively minor importance, for in 1968 there were only 6109 trees and tree numbers were similarly declining.

**Factors favouring development of symptoms**

It is evident that there is some factor which influences symptom expression of green crinkle. For example, it has been reported from New South Wales (Anonymous 1960) and Tasmania (Johnstone & Martin 1968) that trees which show symptoms in one season may carry normal fruit in the next. A similar phenomenon occurs in New Zealand, as of 137 'Lord Wolseley' trees surveyed by officers of the Department of Agriculture in mid-Canterbury, 41 percent of the trees showed symptoms in 1961, 20 percent in 1962, and 26 percent in 1963.

It has been suggested by Pares & Hutton (1961) that cool spring weather may favour symptom expression. Thomas (1961) found that in California symptoms failed to appear on infected trees in most years and concluded that warmer weather tended to suppress symptoms. This contention was supported by the fact that in one orchard symptoms were relatively severe in two years when temperatures were below average from February to July inclusive in every month except March of one of the years. However, a study of the temperature records for mid-Canterbury for September, October, and November during 1961, 1962, and 1963 did not reveal any differences which could explain why the incidence of symptoms was so much greater in 'Lord Wolseley' trees during 1961 than in the following two years. But suppression of symptoms by warm weather could explain why symptoms are rare on 'Granny Smith' in Queensland (Shea 1964) and of relatively high incidence on this cultivar in Tasmania (Johnstone & Martin 1968) and New Zealand.

Observations in New Zealand suggest that symptoms of green crinkle become most evident on trees which lack vigour. The incidence of symptoms on 'Granny Smith' trees grown in the fertile soils of Hawke's Bay appears to be lower than in most other districts. Budwood taken from vigorous and
apparently healthy 'Granny Smith' trees in this district produce trees which, when planted under less favourable conditions in other areas, sometimes develop symptoms in their early years of fruiting. It has been found, too, that the apparently healthy Hawke's Bay trees begin to develop symptoms as they become older and less vigorous. In some Hawke's Bay orchards where trees in hollows have suffered from root damage because of a high water table green crinkle symptoms have frequently developed. In Hawke's Bay in 1972, after an abnormally wet winter in which many trees died from root damage and many others must have been adversely affected, incidence of symptoms was much greater than normal on 'Granny Smith' and other cultivars.

At the DSIR Oratia Research Orchard, Auckland, symptoms began to appear in a 20-year-old block of 'Granny Smith' trees originally propagated from a Mt Albert tree which had never shown symptoms. Atkinson et al. (1965) concluded that the original tree must have carried a mild strain of green crinkle which had mutated to a more severe strain or that symptoms were expressed because of a climatic difference. However, another explanation could be a reduction in vigour of trees grown in the heavy gumland clay soil of the Oratia Orchard.

FIELD SPREAD

A survey of the literature has not revealed any report of insect transmission of green crinkle. McCrum et al. (1960) in their review of apple virus diseases reported that no insect transmission of green crinkle had been observed and that field spread was restricted to the use of infected propagating material. Kristensen (1963) also stated that no indication of insect transmission had been obtained, but that slow spread occurred in some orchards. Atkinson (1971) considered that the appearance of the disease on mature trees indicated the possibility of an insect vector, although none had been found. However, the development of symptoms on mature trees could be explained by the mutation of a mild or latent strain to a more severe one or by the effect of declining vigour of aging trees.

The seasonal variation symptom expression reported by a number of writers (Anonymous 1960; Pares & Hutton 1961; Thomas 1961; Johnstone & Martin 1968) makes it difficult to determine whether field spread occurs. This difficulty is well illustrated by the already mentioned survey carried out in blocks of 'Lord Wolseley' trees in mid-Canterbury.

CONTROL

After the recognition of green crinkle in New Zealand an attempt was made to ensure that, by selection of clean propagating material, all young trees for new plantings were free from this disease. As there was no evidence that green crinkle was present in any of the commonly used rootstocks, it was possible to confine selection to budwood trees. For most cultivars the selection of budwood trees free from symptoms gave adequate control, but difficulty was experienced in selecting 'Granny Smith' trees free from infection. The introduction of heat treatment and heat treatment-tip propagation methods for eliminating viruses and mycoplasma provided possibilities for more positive means of controlling the disease in nursery trees.

Elimination of green crinkle from infected trees

Before the introduction of the heat treatment-tip propagation method an attempt was made to eliminate green crinkle by heat treatment alone. During 1956, six small 'Dunn's Favourite' trees, each infected with a severe strain of green crinkle, were held in a heat treatment chamber at 38° ± 1°C for 40 days. After heat treatment four buds from each tree were worked to individual M IX apple rootstocks. Also, four M IX rootstocks were worked with buds from an untreated infected 'Dunn's Favourite' tree. On fruiting, all trees showed typical green crinkle symptoms, there being no distinguishable difference in severity of symptoms on trees propagated from treated and untreated trees.

As heat treatment alone failed to eliminate green crinkle from infected trees, a trial was carried out using heat treatment followed by tip propagation. In March 1964, eight apple seedlings were worked under glass with buds from a 'Dunn's Favourite' tree showing severe green crinkle symptoms. In the following season the resulting 'Dunn's Favourite' trees were placed in a heat chamber held at 38° ± 2°C. After treatment for 28 days two tips were removed and grafted to young apple seedlings and after a further 4 days two more tips were removed and grafted to seedlings. In the following year six buds from each of three of the grafted trees were worked to M IX rootstocks. The first fruits, produced in 1969, were free from symptoms, as were those produced during the following three seasons.

Before and after treatment, trees were tested for the presence of viruses and mycoplasma other than green crinkle. The original tree was infected with apple rubbery wood, stem pitting, chlorotic leaf spot, and flat limb. After treatment, the spy decline symptom of stem pitting virus was detected in three of the trees. This suggests that green crinkle is one of the diseases which is comparatively easy to eliminate by the heat treatment-tip propagation method.

In New Zealand, apple trees free from known viruses and mycoplasma have been obtained for most important commercial cultivars by the heat
treatment–tip propagation technique (Wood 1973). Early difficulties were experienced in applying this method to trees of 'Granny Smith'. Workers in Queensland had made better progress and kindly supplied us with 'Granny Smith' wood freed from known virus and mycoplasma diseases. More recently a spur type 'Granny Smith' selection has been successfully heat treated and tip grafted in Auckland.

Budwood from trees freed from known viruses and mycoplasma in New Zealand and from 'Granny Smith' trees produced from the Queensland material has been supplied to the New Zealand Fruitgrowers' Federation nursery, a major supplier of nursery trees to commercial growers, and to the Horticulture Research Station of the Ministry of Agriculture and Fisheries, which produces trees to supply budwood to other nurseries. It is therefore intended that within the next few years all young apple trees of the important commercial cultivars planted in New Zealand should be free from green crinkle and other known virus and mycoplasma diseases.

Acknowledgments

Officers of the Ministry of Agriculture and Fisheries who kept us informed of the development of symptoms in the field, carried out surveys to determine the incidence of green crinkle, forwarded fruit specimens, and supplied scion material for experimental trials.

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