Crop & Food Research Confidential Report No. 763

Potato wart: the disease in New Zealand, the national eradication programme, and methods of control

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November 2002

A report prepared for
NZ Vegetable & Potato Growers' Federation Inc.

Copy 2 of 2 (Series IV)

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1 Executive summary

Potato wart (caused by *Synchytrium endobioticum*) was first recorded in a home garden near Invercargill City in 1970. Since then the disease has been reported on a total of 41 properties, all home gardens. By far the majority of the records have been from Invercargill City, but several confirmed occurrences of the disease have been from properties outside Invercargill, over a widespread area as far north as Oamaru. The latest report of the disease was recorded as "eradicated" in 2002.

In this report, the national approach to eradication of potato wart in New Zealand is assessed. The disease has remained confined to home gardens, and reports of potato wart have been rare, suggesting that the eradication programme, though apparently not strictly formalised, has been effective in preventing spread of the disease. Several recommendations are made relating to the current approach to eradicating the disease and possible routes for transmission of potato wart to commercial potato-growing operations are considered. The report also summarises general information on potato wart, including the biology of the pathogen, disease symptoms and control methods.

1.1 Recommendations on the national potato wart eradication programme

1. Consideration should be given to developing a more formal and documented New Zealand Potato Wart Eradication Procedure than is currently in place.
2. Active potato wart education and awareness programmes should continue, and should be reinforced at regular intervals. This activity should be aimed at both the general public (especially home gardeners) and commercial potato growers. This would help to ensure that these groups are likely to recognise and report any new occurrence of the disease. Incorporating these components into a potato wart eradication programme would increase the likelihood of early detection, and allow rapid response to any new outbreaks.
3. Trace back/trace forward investigation of outbreaks of potato wart should become an integral part of the eradication programme for the disease.
4. Skilled personnel should carry out regular potato wart surveillance projects. This would raise the profile of the disease, helping to ensure that eradication procedures continue to be effective, and may also enhance early detection of any new outbreaks of the disease.

5. The limited information available on the epidemiology of potato wart suggests that cool temperatures and moderate rainfall (soil moisture) favour the disease. Surveillance efforts should remain focused on southern New Zealand, both because all records of potato wart have been from Southland and Otago, and because climatic conditions in the south are more likely to favour the disease than those in more northern potato-growing areas.

6. Adoption of formalised phytosanitary procedures could be warranted for potato wart in New Zealand. If this was considered worthwhile, the procedures should follow those developed for overseas regions where the disease has been severe (e.g. EPPO 1999).

7. If potato wart became more widely established than at present, and if the disease became established in commercial fields, eradication would be difficult and very costly. Furthermore, presence of the disease would severely jeopardise exports of fresh or seed potatoes from New Zealand to other countries. Continued active monitoring and steps to eradicate the disease are therefore strongly recommended.

1.2 Conclusions

A total of 41 confirmed records of potato wart have occurred in New Zealand, all from home gardens, and all from the south of the South Island. The “informal” potato wart eradication programme that applies in this country, and the probable lack of movement of seed potatoes or soil from private gardens to commercial potato-growing areas, have prevented movement of the disease from home gardens to commercial potato production.

However, campaigns to maintain awareness of the disease should continue regularly, to maintain public awareness of the disease, to publicise the risks it poses to New Zealand’s potato industries, and to outline possible routes for transmission of wart from home gardens to commercial potato production. Regular potato wart surveillance by experts should be instigated, to enhance the likelihood of early reporting of outbreaks and increase the likelihood of maintaining successful control of the disease.

Formal phytosanitary procedures for potato wart should be put in place. The costs of mounting more rigorous and formal surveillance, investigation and eradication procedures are likely to be considerable, but should be weighed against the potentially severe consequences of new epidemics on commercial potato growing and export.

2 Introduction

Potato wart, caused by the chytridiaceous fungus *Synchytrium endobioticum*, (Schilb.) Percival, was first recorded in a home garden in Invercargill, New Zealand, in 1970. This disease is important because it can devastate potato productivity. The pathogen can survive in soil for many years, and both the pathogen and disease are difficult to control. Potato wart is considered a significant threat to commercial potato production throughout the world, and the disease is the subject of strict quarantine regulations in many countries to counter this threat.

This report reviews the recorded outbreaks of potato wart in New Zealand, and the current potato wart eradication programme in this country. Possible routes of transmission of the disease from areas where it has been recorded to commercial potato production are considered, and the likelihood of this occurring is assessed. As well, recent literature on control of potato wart is briefly reviewed. Some recommendations are made for possible modification of the current approach to containment and eradication of potato wart in New Zealand. A brief description of the disease is also included.

This report was commissioned by the New Zealand Vegetable & Potato Growers' Federation Inc. Some of the information presented was provided by Ministry of Agriculture and Forestry (MAF) Biosecurity.

3 Recorded outbreaks of potato wart in New Zealand

In an unpublished report, Wilkins (1990) outlined the history of potato wart outbreaks in New Zealand up to 1990. The disease was first reported near Invercargill in 1970. Until then New Zealand was considered free of the disease. For almost 20 years prior to 1970, all potatoes legitimately imported into New Zealand were certified free of wart by countries of origin, and had been grown in post-entry quarantine to ensure that no infection by *S. endobioticum* or other pathogens was present. Since the first record and up until 2002, potato wart has been recorded on a total of 41 properties, all in the south of the South Island (information provided by MAF Biosecurity).

The first report of potato wart (January 1970) was from a home garden on the southwestern outskirts of Invercargill City. A subsequent survey of the southern South Island was then carried out by Ministry of Agriculture and Fisheries officers. This showed that distribution of the disease was "relatively restricted" (Wilkins 1990). All records were from the south of the South Island, and all occurrences were in home gardens. The majority of records were in the early to mid 1970s, with four new records in the decade 1981-1990, six new records from 1991-2000, and a single record in 2001.

Confirmed potato wart outbreaks have been recorded from the following localities (from south to north. Current status of the disease as recorded by MAF Biosecurity is indicated):

Waimahaka (Lat. 46° 31' S; Long. 168° 49' E), one record, eradicated 2002;

Invercargill City (Lat. 46° 25' S; Long. 168° 22' E), 34 records, eradicated 1971-1990;

Mataura (Lat. 46° 12' S; Long. 168° 52' E), two records, eradicated (respectively) 1981 and 1990;

Milton (Lat. 46° 07' S; Long. 169° 58' E), one record, eradicated 1971-77;

Gore (Lat. 46° 06' S; Long. 168° 56' E), two records, eradicated (respectively) 1971-77 and 1992;

Kelso (Lat. 45° 54' S; Long. 169° 14' E), one record, eradicated 1971-77;

Oamaru (Lat. 45° 06' S; Long. 170° 58' E), one record, eradicated 1971-77;

Progress Valley (unknown location), one record, eradicated 1971-77.

Thus, while the great majority of potato wart records are from Invercargill City, the disease has been recorded over a wide region, from Waimahaka in Southland (southeast of Invercargill) to Oamaru in North Otago. All of the records have been from home gardens. The focus of records in Invercargill City may be due to the fact that most come from one particular area that was a market garden before being subdivisded into residential properties (M. Braithwaite pers. comm.). The disease may have spread to other areas from that original site, either on seed potatoes from the original market garden or on seed potatoes or plant material contaminated with infested soil from the home gardens from the residential properties.

The most recent report of a home garden outbreak of potato wart was listed as "eradicated" in 2002 (MAF Biosecurity). Besides this, the previous most recent reports of "eradicated" outbreaks were in 1992 (Gore) and 1990 (Mataura and Invercargill City). No information has been provided to the author on the possible source of the most recent outbreak (in Waimahaka). Furthermore, the files made available to the author by MAF Biosecurity, detailing previous outbreaks going back to the original record in 1970, do not record investigations of the sources of the infestations. The focus of activities was obviously on confirming the identity of the pathogen, communicating with owners of affected properties, attempting to eradicate the disease, and assessing the effectiveness of eradication procedures. Therefore, the author can only speculate on the sources of these outbreaks.

There are at least four possible sources of infection for the latest outbreak:

- The very long period of survival of *S. endobioticum* in soil means that infestation could have occurred several to many years ago, possibly from the original infection focus in Invercargill City (a market garden?).
- Secondly, assuming that the "eradications" in Invercargill City or other areas up to 1992 were effective, then the latest outbreak could have originated from another area that is infested but not yet identified.

- Thirdly infection could have come from the infestations that remain in areas where eradication procedures have been used but have not been completely effective.
- Fourthly, infection could have come from a source outside New Zealand (i.e. a fresh import of the pathogen).

Only careful enquiry relating to the most recent outbreak is probable to reveal the likely source of infection. This may indicate the effectiveness of previous eradication activities, the possibility of new sources of infection, or the likelihood of a new epidemic occurring. Until this information is obtained no firm conclusions can be drawn. This type of follow-up investigation (trace back/trace forward) should become an integral part of the routine procedures that are employed with any new outbreaks.

4 *The MAF potato wart eradication programme*

No fully documented "Potato Wart Eradication Programme" is currently in place in New Zealand. However, a well-recognised procedure has been developed for handling confirmed outbreaks of the disease. If a new outbreak were to occur, the likely procedure to be followed would be similar to that developed during the 1970s when most of the potato wart outbreaks were reported. After confirmed identification of the disease by recognised authorities (e.g. previously by the MAF Plant Diagnostic Service, currently by the MAF National Pest Reference Laboratory), agreement would be reached with the property owner concerned to allow fumigation of the infested area. Financial compensation for destruction or removal and disinfestation of perennial plants from the affected area was provided in the past. Fumigation of the infested area would follow, with appropriate rates of methyl bromide, after adequate preparation of the affected soil, and following recommended procedures to maximise its effectiveness. These procedures have included cultivation of the affected soil into a fine tilth, covering the area with polythene sheeting during fumigation, and ensuring that soil moisture and temperature were in the ranges considered adequate for effective fumigation. Registered fumigation companies carried out the fumigation procedures. Property owner agreement was gained to ensure that no plant or soil material was removed from the property. In early cases, the fumigated areas were planted the following growing season with susceptible potatoes, and the harvested tubers were carefully examined for potato wart. This was done to assess the efficacy of the fumigation.

This procedure was generally very effective for eliminating potato wart from infested areas. In almost all cases where documented results were made available to the author, the fumigation procedures were almost totally effective. In a very few cases, very light infections were found in subsequently planted potatoes, but these were usually recorded as likely to have been grown outside the fumigated areas. A personal communication from Mr Peter Wilkins (Agriquality NZ Ltd) to Mr Barney Stephenson (MAF

Biosecurity) indicated that in only one case was repeat fumigation considered necessary due to inadequate “eradication” of the pathogen.

Listing the status of individual recorded occurrences of potato wart as “eradicated” could be questioned in the strictest sense, as eradication implies complete elimination of viable pathogen inoculum. However, the assumption of eradication is reasonable given experience with the efficacy of methyl bromide fumigations over a large number of cases, overseas reports of the generally excellent efficacy of methyl bromide against *S. endobioticum*, and the rarity and low severity of potato wart infestations in New Zealand after fumigation.

In the early 1970s, severe restrictions were placed on the movement of seed potatoes from the general area where potato wart had been recorded. These restraints were later relaxed for commercial potato seed. But inspection of crops to ensure freedom from wart infection remained as a restriction before seed potatoes were allowed to be moved from Southland areas. These restrictions were quite vigorously contested by commercial producers of seed and ware potatoes, however.

This overall procedure is still likely to be followed in the event of any new records of potato wart (B. Stephenson, pers. comm.). At present, after an authenticated record of potato wart, MAF Biosecurity would commission AgriQuality NZ Ltd to oversee eradication procedures. This task would probably be carried out under the supervision of Mr Peter Wilkins, who has long experience of wart eradication in the Southland region. Further, the report of Wilkins (1990) outlines procedures that would be followed in the case of a new outbreak, and these procedures would be generally adhered to in the handling of a new case of the disease.

The current approach to potato wart no longer includes active surveillance. Instead, the perceptions and observations of the general public are relied on to identify any new outbreaks. Several public awareness activities have been carried out since the first confirmed record of the disease, usually as articles in local newspapers and appropriate journals. A recent (April 2002) low key publicity campaign was instigated by the NZ Export and Potato Trade Committee (Evan Johnson pers. comm.; NZ Export and Potato Trade Committee undated). This involved producing a colour brochure with a photo of a wart-infected potato tuber, and publicising an 0800 number to notify any findings of the disease. Copies of the brochure were circulated to garden centres in the south of the South Island, along with a brief summary of information on the disease. Garden centres were requested to forward copies of the brochure and information to garden clubs in the region. This is the first attempt for many years to publicise potato wart. This type of activity should be repeated at regular intervals to help ensure that public awareness of the disease is maintained at a high level.

No active systematic potato wart surveillance, by expert or experienced personnel, is currently carried out in New Zealand. Regular and expert surveillance for the disease could be instigated.

Adequate potato wart eradication programmes can successfully eliminate the disease. Careful monitoring, and application of strict phytosanitary procedures, has eradicated the disease from some areas in North America

(e.g. from Maryland, USA; Putman & Sindermann 1994). Recent experience in Canada, however, reinforces the need for continued vigilance relating to potato wart. Despite many years of enforcing rigid quarantine and phytosanitary procedures in relation to the disease in Canada, two outbreaks (20 km apart) of potato wart were reported very recently (November 2002) in Prince Edward Island (Anon. 2002).

5 *EPPO Phytosanitary Procedures for* S. endobioticum

The European and Mediterranean Plant Protection Organisation (EPPO) has set out phytosanitary procedures for *S. endobioticum.* These are outlined in EPPO Standard PM 3/59/(1) (EPPO 1999). In summary, this standard outlines procedures, including detailed methods with appropriate references, for sampling and assessing soil (by direct examination for *S. endobioticum* resting sporangia, using bioassays and field testing) for presence of the pathogen and potato wart. Also included are criteria and procedures for partial or complete descheduling of previously infested areas. This system has been developed for commercial potato-growing activities.

The current informal potato wart eradication programme in New Zealand loosely follows the procedures set out in the EPPO Standard. Consideration should be given to adopting this, or a similar, standard for the New Zealand situation, so that a more formal approach is taken to eradicating the disease where it occurs, and "descheduling" of infested areas. It may be very difficult, however, to develop an effective descheduling procedure for home gardens, where changes in property ownership and the necessities of maintaining the viability of commercial operations do not apply.

6 *Recommendations relating to the national potato wart eradication programme*

1. Consideration should be given to developing a more formal and documented New Zealand Potato Wart Eradication Procedure than is currently in place.
2. Active potato wart education and awareness programmes should continue, and should be reinforced at regular intervals. This activity should be aimed at both the general public (especially home gardeners) and commercial potato growers. This would help to ensure that the general public are likely to recognise and report any new occurrence of the disease. Incorporating these components into a potato wart eradication programme would increase the likelihood of early detection, and ensure a rapid response to any new outbreaks.

3. Trace back/trace forward investigation of outbreaks of potato wart should become an integral part of the eradication programme for the disease.
4. Skilled personnel should carry out regular potato wart surveillance projects. This would raise the profile of the disease, helping to ensure that eradication procedures continue to be effective, and may also enhance early detection of any new outbreaks of the disease.
5. The limited information available on the epidemiology of potato wart suggests that cool temperatures and moderate rainfall (soil moisture) favour the disease. Surveillance efforts should remain focused on southern New Zealand, both because all records of potato wart have been from Southland and Otago, and because climatic conditions in the south are more likely to favour the disease than those in more northern potato-growing areas.
6. Adoption of formalised phytosanitary procedures could be warranted for potato wart in New Zealand. If this was considered worthwhile, the procedures should follow those developed for overseas regions where the disease has been severe (e.g. EPPO 1999).
7. If potato wart became more widely established than at present, and if the disease became established in commercial fields, eradication would be difficult and costly. Furthermore, presence of the disease would severely jeopardise exports of fresh or seed potatoes from New Zealand to other countries. Continued active monitoring and steps to eradicate the disease are therefore strongly recommended.

7 *Risk of transmission of potato wart to commercial potato production operations*

There are a number of potential paths for transmission of potato wart from infested home gardens to commercial potato-growing operations. The disease is generally recognised as being transmitted on seed potatoes infected by *S. endobioticum*, or as over-wintering sporangia infesting soil contaminating seed potatoes. Other possible avenues of transmission involve movement of infested soil to uninfested areas on transplanted plants (e.g. on roots or bulbs of perennial plants), or infested soil on implements, machinery and vehicles. Sporangia can survive for very long periods (at least 20 years, and possibly up to 40 years), so soil contamination on plant material or machinery could also harbour infestations for long periods. It is also possible that the disease could be transmitted in wind-blown dust, or in soil in floodwaters moving from infested to non-infested areas. Recent research in Newfoundland, Canada, where potato wart is endemic in home gardens, indicated that resting sporangia are probably carried in wind-blown dust, and in or on vehicles, including cars, vans and trucks (Hampson 1996; Hampson et al. 1996; Jennings et al. 1997). This reinforces the need for

careful restriction of activities that may transmit soil containing *S. endobioticum* inoculum from infested to non-infested areas.

Current practices in commercial potato production are likely to preclude transmission of *S. endobioticum* inoculum from home garden situations to commercial potato growing operations. It is unlikely that farmers would use seed potatoes from wart-infested home gardens. Inoculum could also be transmitted to potato-growing fields as soil contamination on farm machinery, on footwear, as wind-blown dust or in floodwater. The use of certified seed potatoes should minimise the likelihood of transmission of the disease on commercial seed potatoes. Nevertheless, consideration should be given to appropriate publicity campaigns, repeated at regular intervals, to remind farmers of the severe risks that potato wart poses to New Zealand's potato industries, and the possible routes for its transmission to their potato production systems.

The fact that potato wart has apparently been confined to home gardens in the 30 years since it was first recorded is significant. This indicates that the eradication procedures used to date have probably been effective, and have prevented the transmission of potato wart from amateur potato production to commercial potato-growing enterprises.

8 *Description of potato wart, and life cycle of* Synchytrium endobioticum

8.1 *Potato wart, hosts and distribution*

Potato wart is also known by several other names, including black scab, black wart, "cauliflower" disease, potato tumour, potato cancer and warty disease (Franc 2001). *Synchytrium endobioticum* can infect a number of wild *Solanum* spp. (nightshades) in Mexico, and a number of solanaceous plants, including tomato, can be infected after artificial inoculation (CAB International 2001). However, potato (*Solanum tuberosum* L.) is the only known cultivated host under natural field conditions. The distribution of *S. endobioticum* is very wide (CAB International 2001). Potato wart is considered to have originated in the Andean zone of South America, from where it was introduced into Europe in the 1880s. It spread rapidly across Europe, and has been recorded in many European countries, in some Asian and African countries, in North and South America, and in New Zealand (CAB International 2001). However, the disease now has restricted distribution or has been "eradicated" from many areas as a result of the successful application of strict statutory measures that were widely introduced for potato wart control. In New Zealand the disease is recorded as having "restricted distribution – under eradication" (CAB International 2001).

Cases have been recorded overseas where wart-infected crops have yielded fewer healthy tubers than the weight of planted seed tubers. This coupled with the difficulties experienced in controlling the disease, the very high costs of broad-scale eradication, and the very strict quarantine restrictions placed

on countries and regions where the disease is recorded, mean that the disease poses severe threats to large-scale potato production.

8.2 Disease symptoms

Potato plants infected by *S. endobioticum* develop characteristic warts on below ground plant parts, including stems, stolons and tubers (CAB International 2001; Franc 2001). No infections have been noted on roots, however. Wart formation begins as a small, spongy swelling that can occur on stolon tips, tuber initials and on tuber buds ("eyes"). The swellings are initially light in colour, similar to normal stolon or tuber tissue, and may be green if exposed to light. They later darken and are often invaded by secondary micro-organisms, which may lead to partial disintegration of wart tissue. Severe infections of individual tubers can replace almost all tuber tissue with wart material, and gross distortion of tubers resulting from severe infections is a dramatic manifestation of the disease. Above ground symptoms of infection are not usually obvious, although severely infected plants can show reduced vigour, and small greenish warts can develop on aerial buds on stem bases close to the soil surface. Rarely, small warts have been recorded on upper stems, leaves, and flowers.

8.3 Pathogen life cycle, and epidemiology

The life cycle of *S. endobioticum* was outlined in detail by Karling (1964). Wart tissue contains mature resting (winter) sporangia of the pathogen, and these are released in the soil as the wart tissue decays. Zoospores are released from sporangia, and infect buds of developing potato tubers, penetrating the host cells. Each zoospore develops in a host cell as a prosorus, and this undergoes nuclear divisions to develop into a zoosporangium. Numerous secondary zoospores can be produced from these zoosporangia through repeated cycles, causing extensive infection of potato tubers. As winter approaches, zoospores may act as gametes, and fuse in pairs to form zygotes. These infect potato tuber cells and incite excessive cell division of tuber surface tissue. This develops into characteristic warts on tubers. Resting sporangia develop in wart tissue, and these are released into the soil when the tissue decays. Resting sporangia survive over winter and can survive for many years in soil, later releasing zoospores and infecting susceptible host tissue.

There has been only limited research on the environmental conditions that favour potato wart. Hampson et al. (1994) demonstrated in controlled experiments that incidence of the disease was greatest at 15°C, while incidence at 12 and 18°C was only approximately 10% of that at 15°C. They concluded that the narrow range of environmental conditions optimal for potato wart development probably explains the erratic occurrence of field infections. The cool soil temperatures favouring the disease may explain, in part at least, why potato wart has remained confined to southern parts of New Zealand. Frequent irrigation has been shown to inhibit infection, suggesting that excess moisture may interfere with zoospore infection processes, possibly the attraction of zoospores to host tissue. A study of environmental conditions (temperature and rainfall) that favour potato wart in Germany (Stachewicz & Enzian 1998) identified areas where the disease is a

problem for potato production. These areas had mean winter temperatures between 0.2 and 2.5°C, summer temperatures between 16 and 17°C, mean winter rainfall between 270 and 560 mm, and mean annual rainfall between 810 and 1220 mm.

Many different pathotypes of *S. endobioticum* have been identified (at least 21), but the pathotype identity for the New Zealand recorded occurrences of the pathogen is not known.

9 Review of methods for control of potato wart

Recent literature on potato wart has been reviewed as part of this project, with particular reference to control of the disease. Three main methods have been used internationally to control potato wart. These are: application of strict phytosanitary measures, use of resistant cultivars, and chemical controls. These methods are briefly reviewed here.

9.1 Phytosanitary measures

Potato wart control, in all areas where the disease causes concern, has relied upon statutory measures, that usually embody several elements (CAB International 2001):

- Potatoes should be derived from stock known to be free of *S. endobioticum* infestation or infection.
- Potatoes should not be grown in fields where the pathogen has occurred and is still present.
- Plants with roots (including bulbs and tubers) should not be removed from infested areas to non-infested areas.

In practice, this means that extensive systems of "scheduling" of *S. endobioticum* infested fields have been undertaken in areas where the disease has occurred (e.g. in Europe). These systems date back to the first decades of the 20th century when wart epidemics were severe. The EPPO standard (EPPO 1999) recommends a method for "de-scheduling" previously infested areas by determining that the pathogen has disappeared. However, there is still debate as to how soon fields should be de-scheduled because of the extremely long viability of *S. endobioticum* resting sporangia.

The success of strict phytosanitary methods has been mixed. Despite using these approaches for many years in north-eastern Canada, particularly in Prince Edward Island, recent outbreaks of the disease have occurred, preventing export of potatoes from that region of North America (Anon. 2002).

9.2 Host plant resistance

Resistance to wart in selected germplasm is an important element of many potato breeding programmes in Central and Eastern Europe. Of 204 references found on *S. endobioticum*, more than 55% related to descriptions of varieties and cultivars resistant to potato wart, host genetics of resistance, methods for selection and breeding for wart resistance, and sources of resistance. There are numerous reports of excellent levels of resistance (including immunity) in new cultivars developed from these programmes. For example, French lists of new varieties describe numerous cultivars as "immune" to *S. endobioticum*. These include; Kemere, Thalassa, (Anon. 1983), Brettor, Caspar, Fecuva, Jardinor, Rozen, (Anon. 1984), Fanette, Balder, Bornia, Concurrent, Landia, Morgane, Mistral, Odran, Primel and Senator (Anon. 1985). Numerous similar reports have been published over the last two decades from Sweden, Norway, Germany, Russia and the Czech Republic. Resistance is apparently conferred by single dominant genes (Zadina 1983), but different pathotypes of *S. endobioticum* have been reported, so this type of resistance may not be durable.

Resistance to wart is an important component of management of the disease in areas where infestation is endemic. However, it is possible that the pathogen can survive and multiply on wart-resistant plants, so use of these may not reduce soil inoculum levels of *S. endobioticum*. Resistant cultivars have been used as part of phytosanitary regulations for potato wart in other countries, where they are recommended for planting in areas surrounding fields where new outbreaks have been recorded, in an effort to prevent rapid spread of the pathogen. In New Zealand, resistant varieties were issued for sale in Southland retail garden centres during the wart outbreaks of the early 1970s. However, the use of resistant varieties may only mask the presence of the disease, and may not be useful where complete eradication is the objective.

9.3 Chemical control

9.3.1 Soil amendments and additives

Hampson (1985) demonstrated that adding urea to field soil infested with *S. endobioticum* suppressed potato wart, and suggested that this activity was due to stimulation of soil microbial activity and production of ammonia. The same study indicated that changing soil pH did not affect disease expression. Potocek (1991) also demonstrated disease suppression with urea, and indicated that soil applications of calcium cyanamide also reduced the disease. Experiments by Hampson and Coombes (1991; 1995) demonstrated that amending home garden soil in Newfoundland with crab shell meal (up to 80 g/kg soil) can reduce potato wart severity, and that suppression was associated with increased microbiological activity in treated soil. They concluded, however, that there was no proof that these treatments eradicated *S. endobioticum* over the long term (Hampson & Coombes 1995).

9.3.2 *Fungicides*

A Russian study (Dolyagin 1990) tested 307 fungicide chemicals for control of potato wart under field conditions. Of these, only chlorothalonil and "Epidor" (active ingredient unknown) gave complete control of the disease, but mancozeb and some experimental compounds reduced disease severity. Potocek (1991) reported that "Allyspol" and "Nitrosan" (active ingredients of both unknown) reduced disease severity. Bruin and Edgington (1983) noted that *S. endobioticum* is "remarkably insensitive to fungicides". No reports of modern fungicides, known to have excellent activity against other zoospore-producing pathogens were found. Fluazinam and flusulfamide have been shown to be effective against *Plasmodiophora brassicae* (clubroot of brassicas) and *Spongospora subterranea* (powdery scab of potato). Testing these chemicals against *S. endobioticum* could be worthwhile.

9.3.3 *Soil sterilants*

Methyl bromide fumigation has been extensively and successfully used to eradicate *S. endobioticum* in New Zealand and overseas, where potato wart has occurred in home gardens (small areas). Other effective soil sterilants have been dazomet, metam (Potocek 1991), and "carbamide" (Bruin & Edgington 1983). Very high rates of application are required to eradicate the pathogen, and the use of general biocides is probably only practical for small plots. The use of general biocides has not been acceptable for control of endemic potato wart in home gardens in Newfoundland, prompting investigations of alternative control strategies (Hampson & Coombes 1995). If eradication is deemed to be worthwhile and economic constraints do not apply, then large-scale chemical eradication can be used. For example, eradication of *S. endobioticum* from field soil in the USA was achieved in the mid 1950s, but this required 2-10 tonnes/ha of ammonium thiocyanate, or 70,000 litres/ha of formaldehyde (Bruin & Edgington 1983). Such large-scale use of general biocides is unlikely to be acceptable at present, for both economic and environmental reasons.

10 *Conclusions*

A total of 41 confirmed records of potato wart have occurred in New Zealand, all from home gardens, and all from the south of the South Island. The "informal" potato wart eradication programme that applies in this country, and the probable lack of movement of seed potatoes or soil from private gardens to commercial potato-growing areas, have prevented movement of the disease from home gardens to commercial potato production. However, campaigns to maintain awareness of the disease should continue regularly, to maintain public awareness of the disease, to publicise the risks it poses to New Zealand's potato industries, and to outline possible routes for transmission of wart from home gardens to commercial potato production.

Regular potato wart surveillance by experts should be instigated, to enhance the likelihood of early reporting of future outbreaks and increase the likelihood of maintaining successful eradication of the disease. Formalised

phytosanitary procedures for potato wart should be put in place. The costs of mounting more rigorous and formal surveillance, investigation and eradication procedures are likely to be considerable. These should be weighed against the potentially severe consequences of new epidemics for commercial potato growing and export.

11 Acknowledgements

Miss Ros Lister assisted with literature searches related to this project. Dr Barney Stephenson (MAF Biosecurity) and Anna Tier (MAF National Pest Reference Laboratory) provided information and files on potato wart outbreaks in New Zealand. Dr Stephen Ogden (Market Access Solutionz Ltd) provided very useful comment on a draft of this report.

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