Potato Virus Y (PVY) and Potato Leafroll Virus (PLRV):

Literature Review for Potatoes South Africa

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1. Introduction

Aphid-transmitted potato viruses, such as potato virus Y (PVY) and potato leaf roll virus (PLRV), have long been recognized as a major problem in the profitable production of seed potatoes. Planting of PVY- and PLRV-infected seed may result in total yield loss (Radcliffe, 1982; Thomas et al., 1997).

Potato virus Y (PVY) and potato leaf roll virus (PLRV) are the two most important viruses of potato globally (Radcliffe, 1982). Primary infection (current season inoculation with virus) of tubers by PVY increases the number of undersized tubers, while infection with PLRV induces net necrosis in tubers (darkening of the vascular bundle) (Radcliffe & Ragsdale, 2002). This results in losses with respect to yield and quality for commercial producers (Ragsdale et al., 1994). Infection with these viruses also leads to a downgrading of seed lots because of the low tolerances (0-1 %) required by seed certification programmes for high quality seed (Radcliffe & Ragsdale, 2002; South African Seed Certification Programme). In South Africa, Daiber (1965) showed that the incidence of PLRV increased from 0.4 % to 97 % after four plantings. Although tubers with higher virus infection levels (1-4%) are unsuitable as seed potatoes, such tubers may still be used to plant the commercial crop (Ragsdale et al., 2001).

Potato virus management strategies are preventative (reduction of virus inoculum) or therapeutic (reduction of vector (aphid) numbers) (Radcliffe & Ragsdale, 2002). These include spatial and temporal isolation of seed potato crops, mechanical barriers and weed control (Ragsdale et al., 2001). The effective control of potato viruses requires a combination of both management strategies and risk assessment with regard to other pests to establish the best option in a region-specific manner (see Mowry, 1994; Caldiz et al., 2002). For example, the need for virus-free seed potatoes requires a much higher level of management than would be required for processed potatoes (Mowry, 1994).

This review focuses on potato virus Y and potato leaf roll virus, their insect vectors and existing management strategies to control the spread of the viruses in potato crops. Local and international research findings are reviewed and evaluated with specific reference to potato production in a South African context. Areas requiring further research to understand the epidemiology of PVY and PLRV in South Africa are identified.
2. Potato virus Y (PVY)

Potato virus Y (PVY) causes serious damage in potato (10-100 % yield losses) and other solanaceous crops worldwide. The severity of the disease depends on the PVY strain involved, host tolerance, time of infection and environmental factors. In potato, PVY is transmitted to the new crop via seed tubers or through aphid vectors. Primary symptoms caused by PVY may be mild or hardly detectable, which causes problems particularly in potato seed production.

2.1. The disease and virus

Potato virus Y is a Potyvirus (family Potyviridae), and thus belongs to a taxon that comprises the largest and economically most important group of plant viruses (de Bokx & Huttinga, 1981; Büchen-Osmond, 1987). PVY is a single stranded RNA virus. Strains of PVY include PVYO (common strain), PVYN (tobacco veinal necrosis strain), and PVYC (stipple-streak strain, including potato virus C). The main diseases caused by PVY include mild to severe leaf mottling, streak or ‘leaf-drop streak’ (PVYO) with necrosis along the veins of the underside of leaflets (PVYN) and ‘stipple-streak’ (PVYC) (de Bokx & Huttinga, 1981; Harrison, 1984).

2.2. Geographic distribution

The distribution of PVY is global, although some virus strains are restricted to certain continents (de Bokx & Huttinga, 1981; Harrison, 1984). PVYO strains occur worldwide, PVYN strains occur in Europe, parts of Africa and South America, and PVYC strains have been reported from Australia, India, and Europe. The two major strains identified in South Africa are PVYO (common strain) and PVYN (tobacco veinal necrosis strain) (Thompson, 1997). PVY-81 (a strain similar to PVYO) appears to be common in potatoes grown in the Northern Cape region (Thompson et al., 1987), while other strains have been identified in tobacco (Vorster et al., 1990).
2.3. Host range

The host range of PVY is broad, comprising many crop species in the Solanaceae (including tomato, pepper, and tobacco) and some species in the families, Asteraceae, Brassicaceae, Chenopodiaceae (Amaranthaceae), Commelinaceae, and Fabaceae (Tables 1, 2; de Bokx & Huttinga, 1981; Büchen-Osmond, 1987, Fletcher, 2001). Weed species that are suitable hosts of PVY may be important virus reservoirs (Latorre, 1983).

Table 1. Examples of host plants of potato virus Y (PVY)

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Plant recorded from South Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asteraceae</td>
<td><em>Cotula australis</em> (Sieber ex Spreng.) Hook. F.</td>
<td>X</td>
</tr>
<tr>
<td>Asteraceae</td>
<td><em>Senecio vulgaris</em> L.</td>
<td>X</td>
</tr>
<tr>
<td>Brassicaceae</td>
<td><em>Capsella bursa-pastoris</em> (L.) Medik.</td>
<td>X</td>
</tr>
<tr>
<td>Chenopodiaceae (Amaranthaceae)</td>
<td><em>Chenopodium quinoa</em> Willd.</td>
<td></td>
</tr>
<tr>
<td>Chenopodiaceae (Amaranthaceae)</td>
<td><em>Chenopodium giganteum</em> D. Don. (tree spinach)</td>
<td>X</td>
</tr>
<tr>
<td>Commelinaceae</td>
<td><em>Tinantia erecta</em> (Jacq.) Schltdl.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Capsicum annuum</em> L.</td>
<td>X</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Capsicum frutescens</em> L. (hot pepper, chili pepper)</td>
<td>X</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Lycium</em> sp.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Lycopersicon esculentum</em> Mill. (tomato)</td>
<td>X</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Nicotiana glutinosa</em> L.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Nicotiana tabacum</em> L. (tobacco)</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Physalis floridana</em> L. (strawberry-tomato)</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum atropurpureum</em> Schrank</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum chacoense</em> Bitter</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum demissum</em> Lindl.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum tuberosum</em> L. (potato)</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 2. Insusceptible host of potato virus Y (PVY)

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solanaceae</td>
<td>Datura stramonium L.</td>
</tr>
</tbody>
</table>

2.4. Virus transmission

The virus can be transmitted by sap inoculation, grafting and aphids in a non-persistent manner (stylet-borne). Although PVY can be transmitted mechanically, this mode of transmission is usually of minor importance in the field (Ragsdale et al., 2001).

Non-persistent viruses have a loose association with vectors, i.e. virus specificity is not marked and many vectors can transmit the virus. In the case of PVY more than 50 aphid species have been shown to be able to transmit the virus, although some species are more efficient than others (Table 5; Büchen-Osmond, 1987; Ragsdale et al., 2001). The most efficient vector appears to be the cosmopolitan peach-potato aphid Myzus persicae (Sulz.) (Hemiptera: Aphididae) (de Bokx & Huttinga, 1981), which is also known as the green peach or peach-potato aphid.

Viruses that are non-persistently transmitted can be acquired and transferred during very short acquisition and inoculation feeding times. Infective aphids are capable of acquiring PVY within seconds to minutes and able to transmit PVY within seconds of probing an uninfected plant (Harrison, 1984). There is no latent period involved, i.e. the virus can be transmitted immediately after acquisition. As the name suggests, non-persistent viruses do not persist or replicate in the vector, and aphids lose the ability to transmit PVY after having probed one or two uninfected plants following acquisition, unless they feed again on an infected plant (Bradley & Rideout, 1953).

Table 5 lists the aphid species that have been identified as being present near potato fields by researchers of the ARC-Vegetable and Ornamental Plant Institute (ARC-VOPI) in a survey conducted across South Africa (1994-1997) (Thompson, 1997), as well as the aphid species that are known to feed on potato and occur in South Africa. Of the known PVY aphid vectors, 25 species have been recorded in South Africa (Thompson, 1997), 12
of which have been reported to feed on potato (I. Millar, pers. comm.). The relative efficiencies with which aphid vectors transmit viruses have been determined for some of the species (Table 5; see Ragsdale et al., 2001).

Aphids recorded can be divided into colonizing (reproduce on potato) and non-colonizing potato (reproduce on plants other than, and do not establish on, potato) species. Usually colonizing aphid species are more efficient vectors than non-colonizing species. Most of the species listed in Table 5 do not colonize potato. However, when searching for a host, aphids take sap samples from the epidermis cells of plants. These sap sampling probes are sufficient to transmit PVY. Although non-colonizing aphid species may be not efficient vectors, the population density of these aphid species in a potato field can be high, thus compensating for their lower transmission efficiency (Radcliffe, 1982; Robert et al., 2000). Therefore, all species that occur throughout the potato-growing season and that occur consistently across years may be important virus vectors and require monitoring to apply the correct control measures (see DiFonzo et al., 1997).

A recent review by Radcliffe & Ragsdale (2002) highlighted the importance of vector biology when attempting to understand and control the spread of potato viruses. For both PVY and PLRV, the virus is moved from an inoculum source outside the potato field into the field almost exclusively by winged aphids (Boiteau, 1997). Apterae (wingless aphids) have not been shown to be significant in within-field spread of PVY (Ragsdale et al., 1994).

In cooler, temperate climates most aphids of potato crops overwinter either as eggs on a primary host or as viviparae (wingless aphids bearing living young instead of eggs) in protected sites (Radcliffe, 1982; Radcliffe & Ragsdale, 2002). Primary hosts are usually fruit trees (e.g. Prunus spp.). Secondary hosts, mainly weed species, allow aphid numbers to increase before potato plants are available for colonization and provide a source of migrants to crops (Radcliffe & Ragsdale, 2002). In milder climates, as is the case in South Africa, parthenogenic (asexual) reproduction is likely to be year-round on weeds, available crops (e.g. cabbage) and garden plants, providing an immediate aphid source when potatoes are planted (Daiber & Schöll, 1959; Radcliffe, 1982; Annecke & Moran, 1982).
Although large populations of aphids are able to damage potato plants directly, the economic importance of aphids results mainly from their role as virus vectors (Radcliffe & Ragsdale, 2002; Radcliffe, 1982). To actively manage the economic impact of the aphid vectors, it is essential to know which aphid species occur in a region, the efficiency with which they are likely to transmit the viruses to potato plants and to understand vector biology (Hanafi et al., 1995; Radcliffe & Ragsdale, 2002; Radcliffe & Ragsdale, 1998). For example, in South Africa, peak *M. persicae* flight activity occurs in October - November and January - February but fluctuates for each locality and across years (see Daiber, 1965).

### 2.5. Disease management

Many aphid species that have been reported as vectors of PVY are incapable of establishing on potato crops (i.e. they are non-colonising aphid species). However, both colonizing and non-colonizing aphid species play an important role as vectors of PVY, the former because they are usually efficient vectors, the latter because they may occur in high numbers, thus compensating for their usually lower PVY transmission efficiency. Therefore, all species that occur throughout the potato-growing season and that occur consistently across years may be important virus vectors and require monitoring for gaining an understanding of the spread of PVY in potato fields (Radcliffe, 1982) and to apply the correct control measures (see DiFonzo et al., 1997). The importance of insect pests also depends on climate, plant age (young plants are more susceptible to net necrosis) and cropping practices (Caldiz et al., 2002; Radcliffe & Ragsdale, 2002). Thus, an understanding of all the factors likely to affect potato production is required to formulate an adequate integrated pest management (IPM) plan for potato seed producers (see e.g. Marsh et al., 1998; Jones, 2004).

### 2.5.1. Crop management and tuber storage

a) Adjustment of planting date and avoidance of vector (spatial and temporal segregation)

Spatial and temporal separation of seed stocks from other crops (e.g. potatoes) that are likely sources of virus inoculum remains one of the most effective preventative
management strategies (Radcliffe & Ragsdale, 2002). The same authors state that a minimum separation distance should be established according to an acceptable level of risk of spread from virus sources to potato fields. Separation distances of 400 m to 5 km have been effective under different management scenarios for seed potato cultivation (Radcliffe & Ragsdale, 2002). However, although maiden flights of *Myzus persicae* alatae seldom exceed 100 m, wind-supported flight may cause aphids to disperse up to several hundred kilometers (Radcliffe & Ragsdale, 2002). Therefore, viruliferous aphids from distant localities may still occasionally colonize isolated potato fields.

Windswept areas along the coast may be almost aphid-free and provide good sites for the location of seed potato fields. Growing all or most seed in a single region, or a group of regions, spatially separated from other crops is practiced in many countries, e.g. Golan Heights in Israel.

Isolation may also include modified planting and harvesting dates (Ragsdale et al., 2001). Planting early if vector species colonise the crop late is a useful strategy. Older plants are less likely to become infected than young plants (mature plant resistance) (Roosen et al., 1997). Although early planting of seed potatoes is an effective strategy in cooler climates where aphids overwinter or abundances are substantially reduced during the winter, the strategy is unlikely to be effective across South Africa. Warmer winters in, for example, the highveld are unlikely to lead to a reduction in aphid numbers. Year-round crops also provide the aphids with a continual food supply so that abundances remain high. Delayed (late) planting is another strategy that has been shown to reduce virus spread by 50 % compared to early plantings (Ragsdale et al., 2001). Tuber yield will, however, be compromised (Boiteau, 1984). Late plantings reduce colonization of the crop by *M. persicae* (early colonizer) but has no effect on *Macrosiphum euphorbiae* (potato aphid) abundances in South Africa.

Growing crops in periods in which aphid vectors are absent or aphid population density is low is another effective strategy to reduce the spread of virus inoculum (de Bokx & Huttinga, 1981). Early planting together with ‘vine kill’ (roguing/haulm destruction) has been effective in The Netherlands; however, such strategies cannot be applied where the growing season is short (Radcliffe & Ragsdale, 2002).
b) Roguing

During rouging, haulms of seed-potato crops are destroyed before maturity so as to restrict virus spread at the end of the growing season. Roguing is effective only when virus incidence is low (~1 %) and when fields are small as each plant requires multiple inspections throughout the growing season (Radcliffe & Ragsdale, 2002). A disadvantage of rouging is that it creates gaps, making the plants more apparent to the aphids (Ragsdale et al., 2001). To be more effective at finding all infected plants, seed pieces cut from the same tuber should be planted together but this is labour intensive and extends the time taken to complete the planting of a field (Ragsdale et al., 2001). Because rouging requires identifying infected plants through symptom expression, cultivars expressing symptoms should preferably be grown instead of symptom-free carriers (Ragsdale et al., 2001). All infective plants need to be removed prior to the arrival of winged aphids (Radcliffe & Ragsdale, 2002).

c) Crop mulching, covers and barriers

Although reflective mulches and sticky yellow sheets may reduce PVY spread (51-80 % in peppers), they are expensive, effective for a short time only (before the canopy closes) and require disposal after use (W. Pett, pers. comm.; Ragsdale et al., 2001). Crop covers may be relatively effective at reducing PVY spread but increased temperatures under the covers negatively impact plant and tuber development, especially where daytime temperatures are high (Ragsdale et al., 2001). Also, infestations under crop covers may go undetected for extended periods of time (Ragsdale et al., 2001). Barrier crops are more effective at reducing PVY spread than insecticides (Radcliffe & Ragsdale, 2002; DiFonzo et al., 1996). If PVY-infected aphids feed on the barrier first, the probability of retaining virus inoculum for transmission to potatoes is low (DiFonzo et al., 1996). Soybean or sorghum barriers (~ 1 m wide) are just as effective at reducing PVY spread as taller crops and should be planted with no gap between the barrier and potato crop (Radcliffe & Ragsdale, 2002; DiFonzo et al., 1996). Barrier crops should have a fallow border to the outside to be apparent to winged aphids (DiFonzo et al., 1996). Soybean is not a host for the virus and it is therefore particularly suitable as a barrier crop, although potato barriers have also been used. These need to be discarded from the seed lots on harvesting. Standard barrier widths have not been established but it appears that barriers of a few
metres wide are effective (DiFonzo et al., 1996). Spraying the barriers with insecticides has no influence on reducing the spread of PVY and should be avoided as the natural enemies of the aphids will be negatively affected.

d) Elimination of virus sources

Weeds (e.g. other solanaceous plants) and volunteer potatoes may be sources of virus inoculum and viruliferous aphids (Thomas & Richards, 2004). Virus inoculum must be reduced by eliminating weeds and volunteer potatoes (Hanafi et al., 1995). Many South African plant species that occur naturally may be sources of virus inoculum. However, when commercial (ware) potato growers plant seed with acceptable levels of virus (1-5 % according to international certification standards) in neighbouring areas, the potato crop itself becomes a greater source of inoculum in the area than weeds (Ragsdale et al., 2001). Virus levels vary depending on the generation and the end use of the crop. In South Africa, these values are zero PVY infection levels for the first two generations and both inspections used for the production of seed potatoes (South African Seed Certification Programme). As is the international standard, much higher levels of virus are acceptable for commercial production (South African Seed Certification Programme). Therefore, potato fields are likely to be the greatest source of PVY inoculum in South Africa. Spraying in wind breaks where aphids numbers build up has also been suggested as an additional management strategy to reduce sources of virus inoculum.

2.5.2. Chemical control

Chemical control of aphid species such as *M. persicae* on overwintering host plants, weeds and within potato and other crops has been shown to be largely ineffectual in controlling the spread of potato viruses (de Bokx & Huttinga, 1981; Radcliffe & Ragsdale, 2002). This is due to the non-persistent nature of PVY transmission, i.e. the virus may be transmitted within the first few seconds of probing an uninfected plant (Bradley, 1954). PVY may therefore be transmitted before the insecticide has time to kill the vector (Radcliffe & Ragsdale, 2002).

However, pesticide usage may be required to curb aphid outbreaks resulting from insecticide applications targeting other insect pests (Radcliffe & Ragsdale, 2002). The
following chemicals have been used to control aphid populations either as in-furrow applications on seed potato plantings (imidacloprid; provides approximately 60-90 days of aphid protection, but has no effect on reducing PVY spread, Boiteau & Singh (1999)) or foliage applications: imidacloprid, methamidophos and thiamethoxam. Most insecticide classes registered for usage on potatoes, such as organophosphates, carbamates and pyrethroids, may cause outbreaks of potato-colonising aphids (ffrench-Constant et al., 1988; Harrington et al., 1989). *Myzus persicae* is resistant to most insecticide classes, making chemical control of this species particularly problematic (Radcliffe & Ragsdale, 2002). A new insecticide, pymetrozine, affects aphid stylet penetration and is likely to be used substantially by the industry in the future (Radcliffe & Ragsdale, 2002). Pyrethroids may cause outbreaks in aphid populations, increasing virus spread (Ragsdale et al., 2001).

In addition, some insecticides are irritating to aphids and increase PVY spread. Extreme care must be taken when applying insecticides in PVY infected areas (Ragsdale et al., 2001).

Where action thresholds of aphid abundances for the prevention of PVY spread in seed potato crops have been established, it has become clear that these vary across regions (PVY spread is not reduced when aphid densities are maintained at the lowest levels possible) (Ragsdale et al., 1994). It is therefore essential to monitor aphid populations within the crop and to establish an action threshold relevant to a particular locality. An important point to remember in aphid control is that of cumulative vector intensity (Basky, 2002; Halbert et al., 2003). This is a function of both the abundance of the aphid species within a field and their efficiency at transmitting the virus (Basky, 2002). Therefore, a rare (low abundance) aphid species may be a serious threat to crops if its transmission efficiency is high, or a highly abundant, less efficient vector may pose a problem regarding PVY spread (Halbert et al., 2003). Also, non-colonising alate (winged) aphids are important vectors of PVY (Radcliffe & Ragsdale, 2002).

The disadvantages of chemical control include the build-up of aphid genotypes that are resistant to chemicals (as mentioned above, *Myzus persicae* is resistant to many classes of insecticides) and environmental degradation (e.g. pollution of water sources (Radcliffe & Ragsdale, 2002)).
By reducing insecticide usage on leaf litter under the plants and on surrounding natural vegetation, predator numbers may be enhanced, thereby reducing aphid numbers.

Certain mineral oils are known to reduce aphid colonization on plants, and thus the transmission of virus diseases (Simons & Zitter, 1980; Martín et al., 2004). Mechanical control with mineral oils reduces the incidence of PVY in tubers (Marco, 1986). Use of mineral oils has resulted in reducing virus spread by more than 50% in Minnesota, USA, without severely affecting natural enemies or the environment (Ragsdale et al., 2001). However, phytotoxicity of mineral oils applied in-field needs to be established (e.g. oils may be phytotoxic when temperatures are high) (see Ragsdale et al., 2001; Martin et al., 2004).

Although whitewash sprays also aid in PVY control, these may be less efficient than net covers and may attract, rather than repel, some aphid species (Marco, 1986).

### 2.5.3. Host plant resistance to the virus

Numerous potato cultivars are available, some of which are symptom-free carriers (infected with PVY and/or PLRV but few symptoms are visible), while a few cultivars appear to be immune or almost immune to PLRV net necrosis (Mowry, 1994). Symptom-free carriers are useful for table and processing potatoes. However, these cultivars are often the bane of seed potato producers as infected plants and tubers are not visibly discernable from uninfected plants, making roguing difficult (Radcliffe & Ragsdale, 2002). The planting of virus resistant potato cultivars is an important avenue of potential control of the viruses but these are costly to develop and need to be durable sources of resistance (Mowry, 1994; Lecoq et al., 2004; Shubert et al., 2004). In addition, the benefits gained (e.g. yield, firmness) from established cultivars also need to be incorporated into the new cultivars (Mowry, 1994).

Enzyme-linked immunosorbent assay (ELISA) and polymerase chain reaction (PCR) tests are the only certain means of ascertaining the infection status of potato tubers, especially symptomless carriers (Robert et al., 2000). ELISA is used in seed certification programmes to process large amounts of samples rapidly and ensures that infection levels in seed potatoes are low (Robert et al., 2000).
2.5.4. Host plant resistance to the vector

Although the planting of aphid resistant cultivars was suggested as a potential virus control strategy (Adams, 1975), only wild potato species are truly resistant to aphids (Radcliffe & Ragsdale, 2002). A study by Raman (1988) indicated that when resistant and susceptible cultivars were exposed to insecticides commonly used in the potato industry, no difference in *M. persicae* mortality was observable.

2.6. Recommendations for seed producing growers: PVY

Potato virus management problems are regional and effective control may only be maintained through co-operation on a regional level between growers (Radcliffe & Ragsdale, 2002). As stated by Ragsdale *et al.* (2001), a reduction of virus inoculum (preventative) and reduction in virus vectors (therapeutic) is required to manage potato viruses. When seed certification programmes (including multiple inspections, roguing and testing of tubers for viruses) are successful, virus inoculum is all but eliminated (Radcliffe & Ragsdale, 2002). This is the case in the US where, in general, PLRV is no longer a major threat to potato growers (pers. comm. Dr W. Pett, Michigan State University). However, on occasions, disease incidence may increase and other measures need to be implemented to reduce disease incidence (Radcliffe & Ragsdale, 2002). Different management strategies are required depending on which virus (PVY or PLRV) is causing the major problem.

2.6.1. Reduction of virus inoculum within the crop

Immediate roguing of plants expressing secondary infection symptoms reduce PVY sources within the crop. Infected plants should be removed before winged aphids arrive. Arrival dates may differ for each region in South Africa. For example, peak *M. persicae* flight activity occurs in October - November and January - February. An additional peak occurs in June/July in Pretoria (see Daiber, 1965). In addition, different species appear to colonise the crop at different times (Daiber, 1962).
2.6.2. Reduction of virus inoculum outside the crop

Potential host plants should be identified and volunteer potato plants eliminated. If virus incidence in the crop exceeds 5%, then the crop is likely to be the greatest source of virus inoculum. Commercial fields located close to seed potato fields are likely to serve as PVY inoculum sources for seed fields.

2.6.3. Monitoring aphid flight to minimize transmission

Alate aphids should be monitored in traps or apterae should be counted on potato foliage to provide an early warning system to growers to initiate mineral oil spraying or early harvest.

2.6.4. Isolation

An effective strategy to curb the spread of PVY is to grow seed potatoes in isolation from commercial potatoes (Radcliffe & Ragsdale, 2002). The separation distance between seed and commercial potato fields will depend on the acceptable level of risk, weather conditions, time when aphids first colonise the crop, crop age at first aphid flight and cultivar, i.e. it varies between localities (Ragsdale et al., 2001; Radcliffe & Ragsdale, 2002). Thresholds to determine when haulm destruction must occur are region-specific and no recommendations can be made in this regard without knowledge of these regional factors.

2.6.5. Barriers

Mechanical barriers (e.g. polypropylene sheets) have been shown to reduce PVY spread (Ragsdale et al., 2001). Barrier crops, planted with a fallow border to the outside and without a gap between it and the crop, will likely reduce PVY spread.
2.6.6. Insecticides

Insecticides do not act quickly enough to reduce PVY spread as aphids usually transmit the viruses before they die. Mineral oils may be effective.

3. Potato leaf roll virus (PLRV)

Potato leaf roll virus (PLRV) is one of the most damaging viruses of seed, processing and fresh market potatoes globally. The virus is transmitted naturally through aphid vectors. Infection of potato with PLRV may cause yield losses through stunting of plants and a reduction in tuber number and size. In addition, infection can lead to internal net necrosis, resulting in tubers being unsuitable for processing. Furthermore, PLRV infection in seed potato crops leads to rejection from certification schemes if the rate of infection exceeds tolerance levels (Ragsdale et al., 2001; Radcliffe & Ragsdale, 2002).

3.1. The disease and virus

Potato leafroll virus (genus Polerovirus, family Luteoviridae) is a single-stranded RNA virus (Harrison, 1984). Strains from potato have been determined based on the severity of symptoms induced in Solanum tuberosum (potato), Physalis floridana and Montia perfoliata, as well as by ease of transmission through M. persicae (Harrison, 1984). However, these strains did not differ antigenetically (Tamada et al., 1984).

Symptoms of PLRV through primary infection (current season inoculation) in potato plants include pallor or reddening of leaf tips, which may roll and become erect. Secondary symptoms in plants grown from infected potato tubers include stunting of shoots and leaflets rolling upwards, starting with the oldest leaves. In plants with primary infection the virus is transmitted through a variable portion of tubers, whereas all tubers on plants with secondary infection are viruliferous (Harrison, 1984).

3.2. Geographic distribution

The distribution of PLRV is global (Harrison, 1984).
3.3. Host range

The majority of known hosts of PLRV belong to the Solanaceae. Non-solanaceous hosts have been reported from a few species belonging to nine plant families. These include the Amaranthaceae (Chenopodiaceae), Brassicaceae, Malvaceae, Asteraceae, Cucurbitaceae, Lamiaceae, Nolanaeae, and Portulacaceae (1). (Harrison, 1984; Thomas, 1984; Natti et al., 1953; Tamada et al., 1984) (Table 3). Examples of non-host plants are given in Table 4.

Table 3. Examples of host plants of potato leafroll virus (PLRV)

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Plant recorded from South Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaranthaceae</td>
<td><em>Amaranthus caudatus</em> L.</td>
<td>X</td>
</tr>
<tr>
<td>Amaranthaceae</td>
<td><em>Celosia argentea</em> L.</td>
<td>X</td>
</tr>
<tr>
<td>Amaranthaceae</td>
<td><em>Gomphrena globosa</em> L.</td>
<td>X</td>
</tr>
<tr>
<td>Brassicaceae</td>
<td><em>Capsella bursa-pastoris</em> (L.) Medik.</td>
<td>X</td>
</tr>
<tr>
<td>Brassicaceae</td>
<td><em>Sisymbrium altissimum</em> L.</td>
<td></td>
</tr>
<tr>
<td>Nolanaeae</td>
<td><em>Nolana lanceolata</em></td>
<td></td>
</tr>
<tr>
<td>Portulacaceae</td>
<td><em>Montia perfoliata</em> Donn ex Willd.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Atropa</em> spp.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Capsicum</em> spp.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Datura stramonium</em> L.</td>
<td>X</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Hyoscyamus</em> spp.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Lycopersicon esculentum</em> Mill. (tomato)</td>
<td>X</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Nicandra physalodes</em> (L.) Gaertn.</td>
<td>X</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Nicotiana clevelandii</em> A. Gray</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Nicotiana</em> spp.</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Physalis floridana</em> L. (husk-tomato)</td>
<td></td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum tuberosum</em> L. subsp. <em>andigenum</em> (Juz. &amp; Bukasov) Hawkes</td>
<td>X</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum tuberosum</em> L. subsp. <em>tuberosum</em> (potato)</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 4. Insusceptible hosts of potato leafroll virus (PLRV)

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brassicaceae</td>
<td><em>Brassica rapa</em> L. subsp. <em>campestris</em> (L.) A. R. Clapham</td>
</tr>
<tr>
<td>Brassicaceae</td>
<td><em>Brassica oleracea</em> L. var. <em>capitata</em> L. (cabbage)</td>
</tr>
<tr>
<td>Brassicaceae</td>
<td><em>Brassica rapa</em> L. subsp. <em>pekinensis</em> (Lour.) Hanelt (Chinese cabbage)</td>
</tr>
<tr>
<td>Fabaceae</td>
<td><em>Pisum sativum</em> L. (pea)</td>
</tr>
<tr>
<td>Brassicaceae</td>
<td><em>Raphanus sativus</em> L. (radish)</td>
</tr>
<tr>
<td>Asteraceae</td>
<td><em>Senecio vulgaris</em> L.</td>
</tr>
<tr>
<td>Fabaceae</td>
<td><em>Vicia faba</em> L. (broad bean)</td>
</tr>
</tbody>
</table>

3.4. Virus transmission

The virus is not transmitted by manual inoculation with sap nor through true seed but is transmissible by vector aphids and by grafting. Because PLRV is not seed-transmitted, annual weeds are not thought to be an important virus source in spring in regions where winters are cold (Thomas, 1983). However in warmer regions the situation may differ and perennial and tuber-forming weeds can harbour PLRV through winter (Natti *et al.*, 1953; Fox *et al.*, 1993).

PLRV is transmitted by aphids in a persistent circulative non-propagative manner (Thomas, 1987; Harrison, 1984). As is the case generally with persistently transmitted viruses, the longer the acquisition and inoculation times, the higher is the rate of transmission of PLRV. Persistently transmitted viruses usually have a narrow range of vectors, are passed on when the vectors moult and need a latent period. PLRV does not replicate in the vector (circulative-non propagative) virus.

Vectors must feed on the phloem tissue of potato plants. PLRV is therefore only transmitted by aphids colonizing potatoes and, once acquired, the aphid remains infective for life (Radcliffe & Ragsdale, 2002; Harrison, 1984). Aphids colonizing the potato crop require 1.6 – 15 minutes to acquire PLRV from an infected plant and become infective within 8 – 72 hours (latent period) (Radcliffe, 1982; Radcliffe & Ragsdale, 2002).
The efficiency of virus transmission by aphids varies and depends on the species, and within a species on the biotype, morph or instar, e.g. nymphs or adults of winged or apterous viviparous (wingless aphids bearing living young instead of eggs) species, on viviparous morphs producing sexual forms (gynoparae) and on sexual morphs themselves (oviparae and males) (Table 5).

_Myzus persicae_ is the most efficient vector of PLRV and is able to acquire more of the virus and transmit it faster when feeding at comparatively higher temperatures (Syller, 1994; Bradley & Rideout, 1953). The role of _Macrosiphum euphorbiae_ in PLRV transmission is variable; many populations are poor vectors while the species has been reported as an important vector in the early-season spread of the virus at some localities (see Radcliffe & Ragsdale, 2002). Generally, monitoring of aphid populations in the field for PLRV control focuses on _M. persicae_ (Ragsdale _et al._, 1994). In South Africa, nine aphid species known to transmit PLRV have been recorded in the vicinity of potato fields (Table 5). Unlike PVY, within-field spread of PLRV is usually by apterae (wingless aphids) (Boiteau, 1997; Mowry, 2001). However, Radcliffe & Ragsdale (2002) suggest that within-field spread of PLRV may yet be associated with alatae and not apterae because maiden flights of alate _M. persicae_ seldom exceed 100 m.

### 3.5. Disease management

#### 3.5.1. Crop management and tuber storage

a) Adjustment of planting date and avoidance of vector (spatial and temporal segregation)

As for PVY, isolation of seed and commercial potatoes is an effective strategy to curb the spread of PLRV (Radcliffe & Ragsdale, 2002). The separation distance varies between localities but is likely to be > 30 km (Ragsdale _et al._, 2001; Radcliffe & Ragsdale, 2002). Changes in the cropping practices in a region must be noted as these may reduce the effective isolation distance.
Isolation may also be via modified planting and harvesting dates (Ragsdale et al., 2001). Delayed planting (planting after the colonizing flight of *M. persicae*) has been suggested as a potential PLRV control strategy (Hanafi *et al*., 1995; Boiteau, 1984). Yield and tuber size are reduced with delayed plantings.

b) Roguing

In the Pacific Northwest, USA, twelve plants surrounding the infective PLRV-infected plant need to be removed as neighbouring plants may be infective but not symptomatic (Mowry, 1994). This is unlikely to occur in the field where symptoms are mild and/or fields are large (Mowry, 1994).

c) Crop mulching, covers and barriers

Whitewashes substantially reduce PLRV incidence in tubers, but are less efficient than white net covers (Marco, 1986). However, crop covers reduce yield (Marco, 1986) and where infective aphids penetrate the covers, virus spread is often dramatic because of delayed control measures. This risk of increased virus spread under covers and the cost of crop covers make this management strategy unlikely to be adopted at large scales. Mechanical barriers (sticky polyethylene sheets) may reduce PLRV spread by 38% (Marco, 1981).

d) Elimination of virus sources

Weeds and volunteer potatoes may be important sources of viruliferous aphids and PLRV inoculum (e.g. Hanafi *et al*., 1995; Thomas & Richards, 2004). Many South African plant species that occur naturally may be sources of virus inoculum. However, when commercial potato growers plant seed with acceptable levels of virus (1-4% according to US certification standards) in neighbouring areas, the potato crop itself becomes a greater source of inoculum in the area than weeds (Ragsdale *et al*., 2001). In South Africa, these values are zero for PLRV levels for the first two generations and both inspections used for the production of seed potatoes (South African Seed Certification Programme). In line with international standards, higher levels are virus are acceptable for commercial
production in South Africa (South African Seed Certification Programme). Therefore, potato fields are the likely greatest source of PLRV inoculum in South Africa. Crop rotation is an important mechanism used to reduce the quantity of volunteer potato plants in the Pacific Northwest but farms need to be separated by large distances and three to four year rotation cycles need to be maintained (Mowry, 1994).

e) Tuber storage management

The probability of net necrosis in tubers increases to a maximum at 90 days of storage (Marsh et al., 1998).

3.5.2. Chemical control of vectors

Systemic insecticides and/or accurately timed foliar insecticide applications are useful to reduce within-field spread of PLRV, especially if colonizing aphids are virus-free on arrival. Some insecticides (e.g. the carbamate aldicarb) control within-field spread of PLRV by apterae but do not prevent transmission by alatae (see Ragsdale et al., 2001). The chloronicotinyl class of insecticides (imidacloprid) and the new insecticide pymetrozine appear effective at controlling within-field spread of PLRV (Ragsdale et al., 2001). Imidacloprid applied systemically reduces PLRV spread (Boiteau & Singh, 1999).

Recommendations for the timing of insecticide applications for PLRV control in seed potatoes are affected by aphid biology and arrival time relative to crop age (Ragsdale et al., 2001). Vector control is usually focused primarily on M. persicae, as it is the most efficient vector species colonizing potatoes (Ragsdale et al., 1994). For PLRV, action thresholds of aphid abundances for seed potato crops are 10 M. persicae apterae per 100 leaves, but such thresholds are region-specific (Mowry, 1994; Ragsdale et al., 1994). Weekly monitoring may occur at too coarse a scale to provide rapid results to apply control measures (aphid populations expand rapidly and exponentially (Radelcliffe & Ragsdale, 2002). A 3-4 day aphid monitoring programme, instead of 7 days, has been recommended by some authors (Mowry, 2001). This provides sufficient time to apply foliage sprays before aphids have exponentially spread the virus to plants throughout the fields (Mowry, 2001). A zero-tolerance policy has been advocated to prevent the spread of PLRV in seed potatoes in Idaho (Mowry, 2001). However, such intensive insecticide usage is likely to contribute to insecticide resistance in the future (Mowry, 1994).
negative consequences of the uncontrolled use of chemicals have led to the development of economic risk assessments where the end-use of the potatoes is taken into consideration in an attempt to minimize insecticide applications (Marsh et al., 1998).

Antifeedants and repellants such as neem (azadirachtin) have also been used with varying results to slow the spread of PLRV (van den Heuvel, 1998; Nisbet et al., 1996). These may be applied as oil formulations (Cranshaw & Baxendale, 2005).

3.5.3. Host plant resistance to the virus

Commercial potato cultivars do not show significant resistance (immunity) to PLRV but some (e.g. ‘Norgold Russet’) are resistant to tuber net necrosis (Mowry, 1994; Thomas et al., 2000). This review is not concerned with establishing to which degree the potato cultivars currently grown in South Africa are susceptible to PLRV.

3.5.4 Host plant resistance to the vector

Genetically modified potato cultivars may decrease PLRV spread between plants by Myzus persicae (Thomas et al., 2000).

A summary of distribution, host range, symptomatology, vectors, mode of transmission and control of PVY and PLRV is provided in Table 6.

3.6 Recommendations for seed producing growers: PLRV

3.6.1. Reduction of virus inoculum within the crop

Plants expressing secondary infection symptoms should be removed to reduce within crop virus inoculum. Symptom-free carriers should not be planted in seed potato regions, thereby reducing the ease of roguing.

3.6.2. Reduction of virus inoculum outside the crop

Virus inoculum must be reduced by eliminating weeds and volunteer potatoes (Hanafi et al., 1995).
3.6.3. Monitoring aphid flight to minimize transmission

Alate aphids should be monitored in traps or apterae counted on potato foliage to provide an early warning system for growers to initiate mineral oil spraying or early harvest.

3.6.4. Isolation

Isolate seed and commercial potato production. Effective isolation distances need to be established after determining cropping practices in the region.

3.6.5. Barriers

Mechanical barriers (sticky polyethylene sheets) may reduce PLRV spread by 38% (Marco, 1981). Crop barriers may also slow PLRV spread.

3.6.6. Insecticides

Action thresholds based on counts of wingless aphids need to be developed for each region in South Africa where seed potatoes are grown (Ragsdale et al., 1994; Ragsdale et al., 2001). Clear guidelines need to be formulated to prevent the over-use of chemicals that will likely lead to the development of increased resistance in aphid populations and to further outbreaks. Minimizing damage to the environment is also a concern.

3.6.7. Cultivars

Cultivars should be planted that are not susceptible or are less susceptible to net necrosis but that are still symptomatic (or else roguing is affected).

The incidence of PLRV and PVY in tubers is presently high in certain growing areas (Ben Pieterse, pers comm.). It will potentially take a number of years before the levels of virus inoculum will decline and stabilize to lower levels than are currently experienced and for the epidemic to end once additional control measures are implemented (Radcliffe & Ragsdale, 2002). Over this time, it will be essential for growers to follow the guidelines provided by their managing organization (Potatoes South Africa) and the Seed Certification Programme.
Table 5. Aphid vectors of potato virus Y (PVY) and potato leaf roll virus (PLRV) recorded in the vicinity of seed potato fields in South Africa and aphid species known to colonize potato

<table>
<thead>
<tr>
<th>Species</th>
<th>PVY vector</th>
<th>Percent transmission efficiency of PVY</th>
<th>PLRV vector</th>
<th>Percent transmission efficiency of PLRV</th>
<th>Known to colonize potato</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acyrthosiphon pisum</em> (Harris)</td>
<td>X</td>
<td>3.8 - 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aphis fabae</em> (Scopoli)</td>
<td>X</td>
<td>7.6 - 24</td>
<td>X</td>
<td>not reported</td>
<td>X</td>
</tr>
<tr>
<td><em>Aphis gossypii</em> (Glover)</td>
<td>X</td>
<td>12 - 31</td>
<td>X</td>
<td>4-74</td>
<td>X</td>
</tr>
<tr>
<td><em>Aphis nasturtii</em> Kaltenbach</td>
<td>X</td>
<td>19.0 - 50</td>
<td>X</td>
<td>20</td>
<td>X</td>
</tr>
<tr>
<td><em>Aphis spiraecola</em> (Patch)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aulacorthum circumflexum</em> (Buckton)</td>
<td>X</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aulacorthum solani</em> (Kaltenbach)</td>
<td>X</td>
<td>5.0</td>
<td>X</td>
<td>not reported</td>
<td>X</td>
</tr>
<tr>
<td><em>Brachycaudus helichrysi</em> (Kaltenbach)</td>
<td>X</td>
<td>4.8 - 12.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Brachycaudus rumexicolens</em> (Patch)</td>
<td>X</td>
<td>not reported</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Brevicoryne brassicae</em> (L.)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Capitophorus hippocaes</em> (Walker)</td>
<td>X</td>
<td>3.0 - 3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Diuraphis noxia</em> (Mordvilko)</td>
<td>X</td>
<td>4.0 - 7.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Dysaphis</em> (<em>Pomaphis</em>) spp.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hyalopterus pruni</em> (Geoffroy)</td>
<td>X</td>
<td>13.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hyperomyzus lactucae</em> (L.)</td>
<td>X</td>
<td>0.4 - 17.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5 continued

<table>
<thead>
<tr>
<th>Species</th>
<th>PVY vector</th>
<th>Percent transmission efficiency of PVY</th>
<th>PLRV vector</th>
<th>Percent transmission efficiency of PLRV</th>
<th>Known to colonize potato plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipaphis erysimi (Kaltenbach)</td>
<td>X</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macrosiphum euphorbiae (Thomas)</td>
<td>X</td>
<td>4.0 - 29.0</td>
<td>X</td>
<td>0 - 25</td>
<td>X</td>
</tr>
<tr>
<td>Metopolophium dirhodum (Walker)</td>
<td>X</td>
<td>0.5 – 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myzus ornatus Laing</td>
<td></td>
<td></td>
<td>X</td>
<td>not reported</td>
<td></td>
</tr>
<tr>
<td>Myzus persicae (Sulzer)</td>
<td>X</td>
<td>4.7 - 71.1</td>
<td>X</td>
<td>2.4 - 83.8</td>
<td>X</td>
</tr>
<tr>
<td>Rhopalosiphoninus latysiphon (Davidson)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rhopalosiphum maidis (Fitch)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhopalosiphum ruftiabdominalis (Sasaki)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rhopalosiphum padi (L.)</td>
<td>X</td>
<td>0.5 - 11.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schizaphis graminum (Rondani)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitobion sp.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitobion avenae (F.)</td>
<td>X</td>
<td>0.06 - 1.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitobion fragariae (Walker)</td>
<td>X</td>
<td>0.09 – 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smynthurodes betae Westwood</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uroleucon sonchi (L.)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Thompson, 1997; Ragsdale et al., 2001
* I. Millar (pers. comm., ARC-PPRI. Although all of the species marked are known to colonize potato, some have not been collected on potato in South Africa, which could be a reflection of collecting effort).
* Ragsdale et al., 2001;
* This species has not been recorded from potato
Table 6. Tabulated summary of distribution, host range, symptomatology, vectors, mode of transmission and control of i) Potato virus Y and ii) potato leafroll virus

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Host range</th>
<th>Symptoms</th>
<th>Identified vectors</th>
<th>Transmission</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Potato Y potyvirus (PVY)</td>
<td>Worldwide, in potato and outdoor crops of pepper, tobacco and tomato in warmer countries (de Bokx and Huttinga 1981)</td>
<td>a) leaf mottling, b) ‘leaf drop streak’ with vein necrosis, c)‘stipple-streak’</td>
<td>Myzus persicae (most efficient), Aphis fabae, Macrosiphum euphorbiae, Myzus (Nectarosiphon) certus, Myzus (Phorodon) humuli, Rhopalosiphum insertum</td>
<td>-Non-persistent -Mechanical inoculation (25 spp of aphids) -grafting -no helper virus required</td>
<td>Insecticides ineffective i) avoid infection ii) avoid growing crops near established crop of same species iii) roguing iv) spray with mineral oils to reduce transmission v) breed for resistance vi) reflective surfaces and sticky yellow sheets</td>
</tr>
</tbody>
</table>
Table 6 continued

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Host range</th>
<th>Symptoms</th>
<th>Identified vectors</th>
<th>Transmission</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>ii) Potato leafroll virus (PLRV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worldwide in most potato crops; tomato yellow top diseases reported in some countries but not determined that all caused by PLRV</td>
<td>Potato (Solanum tuberosum)</td>
<td>Potato: Primary: pallor/reddening of leaf tips, may become rolled; Secondary (plants grown from tubers): shoot stunting, upward rolling of leaflets esp. lower leaves, may develop marginal necrosis; internal net necrosis may develop in tubers with primary/secondary infection</td>
<td>Several spp reported to transmit virus; <em>Myzus persicae</em> (most efficient), * Macrosiphum euphorbiae* (good vector of Australian yellow top isolates)</td>
<td>-not transmitted by manual inoculation -persistent -transmissible by aphid vectors and grafting</td>
<td>i) select tubers from symptom-free clones of mother plants ii) heat treatment of tubers iii) grow seed-potato crops where vectors are few or arrive late in growing season or unfavourable weather conditions for aphid activity iv) roguing v) apply insecticides to minimize aphid activity vi) harvest/destroy haulms (early ‘vine kill’) before virus pass from shoots to tubers vii) isolate healthy seed-potato crops from infected viii) Plant field-resistant cultivars ix) Assess tuber health after harvest (serological tests esp. ELISA)</td>
</tr>
</tbody>
</table>


leaf drop streak = necrosis, starts as spots or rings on leaflets, may cause leaves to collapse and drop from plant or remain hanging on stem
stipple streak = necrotic lesions and streaks on leaves and variable streaking on petiole and stems
4. References


