Final Report

Viruses of national importance to the vegetable industry

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Content

Summary

The vegetable industry has funded a diverse range of research, development and extension activities aimed at minimising the impact of viral diseases, which continue to have a significant impact on productivity.

Estimates of economic losses from virus diseases include 5% loss ($7.2M) in greenhouse and field grown capsicum from Tomato spotted wilt virus and between 5% and 10% loss in vegetable cucurbits (excluding cucumbers) from potyvirus infection. This equates to a loss of $15 to $30M based on 2014 crop value statistics.

Cucumber green mottle mosaic virus caused an estimated loss of $45M to the Northern Territory watermelon industry following detection of the virus in 2014.

These estimates are based on data from disease surveys, expert opinion and discussions with growers and industry crop protection specialists. The figures do not account for additional losses from factors such as contracted growing season due to virus epidemics, reduced variety selection due to virus susceptibility and increased packing costs to remove virus affected fruit.

The purpose of this project was to review viruses of national importance to the Australian vegetable industry with emphasis on providing recommendations for future investments.

The project was largely undertaken as a desktop study with a literature review of viruses of importance to the industry considered in terms of epidemiology, host range, transmission, economic impact and current and potential management methods.

A key activity of the project was a two day workshop in May 2016 in Brisbane where nine plant virologists with experience in both the vegetable industry and the biology and management of viruses affecting vegetables met. The group developed a list of viruses of current and potential importance to the industry; developed priority areas for future investment and discussed means of closer collaboration in diagnostics and project development.

Industry stakeholders were invited to contribute to the review through a newsletter article and survey form and also by personal contact from team members.

Outputs

- A literature review on viruses of national importance to the vegetable industry completed
- Overview of diagnostics for detection and identification of plant viruses in Australia
- An article for the AUSVEG weekly update requesting contributions to the review and including a survey form to seek comment on virus diseases , their importance and management
- Eleven key recommendations for future investment in RD&E

Outcomes

The major outcome for the project is enhanced knowledge for future RD&E investment to manage virus diseases of vegetables. Specific outcomes include:

- Confirmation that virus diseases continue to cause economic impact to vegetable producers and broader supply chain
- Identification of potential RD&E aims to reduce the economic impact in the short, medium and long-term though improved diagnostic delivery, strategic disease management options and extension of new information to industry

There were ten specific recommendations from the project. The recommendations cover the following general topics:

- The virus groups identified as currently having most impact and where future investment is required to reduce economic impact were the tospoviruses, particularly tomato spotted wilt virus, and the potyviruses, in particular those infecting cucurbits.
- Developing projects based on the principles of area wide management of viruses and vectors was seen as a priority as these projects provide opportunity for sustainable long-term management, allow greater cross industry participation and provide ownership among participants, thus providing a better climate for adoption and change.
- A lack of detailed R&D on the major virus vectors was identified as gap in our knowledge base and one requiring increased investment.
- The key virology diagnostic laboratories to develop closer collaborations to provide a more co-ordinated delivery of diagnostic services to the vegetable industry.
- The provision of information on virus disease management was seen as a continuing high priority for future investment. This information should be provided where possible with other crop protection and agronomy packages to assist in effective delivery.
- Given the reliance of the vegetable industry on high levels of imported planting seed for all major crops, and the regular incursion of seed transmitted viruses, further investment is recommended on investigating and mitigating the role of seed as a pathway for viruses.

Keywords

Virus; vegetables; research; extension

Introduction

Management of virus diseases is challenging for several reasons, including active and efficient insect vectors for many viruses, the often wide range of crop and weed hosts of both viruses and vectors and the lack of curative measures once infection has occurred. Virus disease management must aim at preventing or reducing disease introduction and/or incidence in crops thus minimizing the economic impact.

The majority of viruses infecting vegetable crops in Australia are transmitted by insects, with aphids, thrips and whitefly being the main vectors. Examples include the aphid transmitted Papaya ringspot virus, Tomato spotted wilt virus transmitted by several species of thrips and Tomato yellow leaf curl virus which has the whitefly *Bemisia tabaci* as the vector. Several viruses lack a specific insect vector but are efficiently dispersed by seed and/ or contact. A good example is the recently detected Cucumber green mottle mosaic virus which is seed borne in several cucurbit species and easily spread by contact and mechanical damage.

Specific data on economic losses due to virus diseases in the vegetable industry is minimal. However, estimates can be made based on data from disease surveys, reference to experienced crop protection specialists and growers and some published information.

These estimates include a loss of 5% or $7.2 M in greenhouse and field capsicum production from Tomato spotted wilt virus. Cucurbits, excluding cucumber, have estimated annual losses of between 5% and 10% ($15.3M to $30.6M) from potyvirus infection (Papaya ringspot virus and Zucchini yellow mosaic virus).

Cucumber green mottle mosaic virus (CGMMV) caused losses of about $45M to the watermelon industry in the NT following the detection of the virus in field grown watermelons in 2014.

The virus is currently causing losses of several million dollars to greenhouse cucumber growers in WA and Bundaberg in Queensland.

Following the incursion of Tomato yellow leaf curl virus into south Queensland in 2006 annual losses were estimated at $10 to $15M from yield and quality reductions. The economic viability of the Queensland industry now depends to a large extent on the adoption of virus resistant hybrids.

These estimates of crop losses do not include factors such as restriction of growing season due to frequent virus epidemics, limited variety selections because of virus susceptibility, frequent insecticide applications with often minimal effect on vector numbers and increased packing costs due to removal of virus affected produce on the packing line.

The vegetable industry has funded a diverse range of research, development and extension activities aimed at minimizing the impact of viral diseases. The opportunity exists to review these activities and develop a strategy for future investment to build on this work and the recommendations made.

The purpose of this project was to review viruses of national importance to the Australian vegetable industry with emphasis on providing recommendations for future investments in this area.

The project is an outcome of a broad review of plant health investment in VG 12048 where previous projects were reviewed and recommendations made to assess future investment needs.

The project was largely undertaken as a desk top study with a review of viruses of importance to the industry considered in terms of epidemiology, host range, transmission, diagnostic capacity and current and potential management methods.

A two day workshop was convened where experienced virologists working with the vegetable industry discussed and prioritized the importance and economic impact of viruses infecting vegetables. An outcome from the workshop was a list of recommendations and suggestions on how future investment will contribute towards providing industry with the tools to better manage key virus diseases and thus reduce the economic impact from them.

Although the focus of the study was on endemic viruses, it also identified high priority quarantine pathogens that may be absent or require greater emphasis in the current vegetable industry biosecurity plan. In reviewing the diagnostic capability for the vegetable industry both endemic and biosecurity threats need to be considered in terms of preparedness and resourcing.

The literature review and recommendations are available to a wide audience including vegetable growers, agribusiness staff, industry consultants, research staff in both private and government researchers and industry media.

Methodology

A literature review was prepared in which the important viruses infecting vegetable crops in Australia were evaluated in terms of transmission, epidemiology, host range, distribution, economic importance and current management methods. This was largely done under virus groups as this provides an appropriate way to assess general properties of endemic members and use this to evaluate the likelihood of other members of those groups entering Australia and their potential impact.

Current and future diagnostic methods and resources were assessed are presented in appendix 2.

The following project reports/ project documents were reviewed:

VG 12048 Plant Health Desktop Study 2013

VG0 7128 Integrated viral disease management in vegetable crops 2011

VG 10104 Management of virus diseases in vegetables 2014

VG 10081 Breeding capsicums for tospovirus resistance 2016

VG 03057 Scoping study on the importance of virus diseases in Australian vegetable cucurbit crops 2004

Current projects reviewed:

VT 13003 Improved productivity of fruiting solanaceous crops through area wide management of insect vectored viruses in Bowen.

VT 15013 Improved management options for Cucumber green mottle mosaic virus

VG 14063 Innovative solutions to the management of tospoviruses in vegetables

VG 15073 Characterisation of a Carlavirus of French bean

A project workshop was convened on May 9/10 2016 in Brisbane. Eight virologists with experience in viruses affecting vegetable crops and project delivery for the vegetable industry were invited along with the Hort Innovationprogram leader for crop protection. The participants, program and summary of discussions are provided in Appendix 3.

Participants assisted in refining and prioritising virus diseases of importance in levied vegetable crops in the main Australian production areas, developing strategies for better management and scoping future RD&E.

A survey form was designed and distributed via the AUSVEG weekly newsletter and by individual contact with growers and industry staff. A copy of the survey form and press release are attached.

Outputs

- A literature review on viruses of national importance to the vegetable industry completed (Appendix 1)
- Overview of diagnostics for detection and identification of plant viruses in Australia (Appendix 2)
- An article for the AUSVEG weekly update requesting contributions to the review and including a survey form to seek comment on virus diseases, their importance and management (Appendix 3)
- Key recommendations for future investment in RD&E provided as an appendix to this report (Appendix 4)
- End of project summary to be provided to Hort Innovation and vegetable industry media on acceptance of final report

Outcomes

The major outcome for the project is enhanced knowledge for future RD&E investment to manage virus diseases of vegetables. Specific outcomes include:

- Confirmation that virus diseases continue to cause economic impact to vegetable producers and broader supply chain
- Identification of potential RD&E aims to reduce the economic impact in the short, medium and long-term though improved diagnostic delivery, strategic disease management options and extension of new information to industry

Review of results from previous and current projects investigating virus diseases of vegetables showed ongoing economic impact to the vegetable industry. This impact not only affects the grower, it also affects the broader supply chain and consumers through either disruption of supply and/or lower quality product entering the market. This was re-enforced through discussions with key virologists, seed and chemical company representatives and other stakeholders involved with the industry.

Similar discussions helped to identify key RD&E topics for further investment. A range of activities are required and include experimental work to better understand virus and vector relationships, trial work to evaluate new methodologies for disease management, improving diagnostic processes to accelerate disease identification and extension of new information to industry.

Evaluation and discussion

The project was initiated on the understanding that virus diseases cause economically important crop losses to the vegetable industry and a review was appropriate to recommend future strategies to reduce these losses. Some estimates of these losses are given in the project summary and introduction.

The project workshop was a key component of the project and provided a valuable forum for nine experienced virologists to discuss successes, knowledge gaps and possible future directions.

The draft recommendations were prepared at this workshop and the priority future work areas identified.

The two day workshop was a valuable meeting and vital in the success of the project. The meeting allowed constructive and wide ranging interaction between virologists with both broad and detailed experience with viruses and the vegetable industry. The group first worked as a team in VG 7128 and have maintained both a formal and informal collaborations for over 10 years.

The two virus groups identified as having the greatest negative economic effect on the vegetable industry were the Tospoviruses, particularly Tomato spotted wilt virus and the potyviruses with the three infecting cucurbits (Papaya ringspot virus, Zucchini yellow mosaic virus, Watermelon mosaic virus) being selected as being the most geographically widespread and damaging.

The Tobamoviruses are also important given that these viruses are generally seed borne and are very easily spread by contact.

Cucumber green mottle mosaic virus (CGMMV) is the tobamovirus of current concern as it has spread substantially since the first detection in field watermelons in the NT in 2014, despite seed testing at the border and rigorous biosecurity responses when detected elsewhere. There is a current national project on CGMMV management and a project on improving the sensitivity of seed testing for the pathogen. Recommendations on future investment on this issue should probably wait until further results are available from current projects.

The outputs from the project were

- a report on viruses of importance to the vegetable industry which focused on important endemic viruses but also noted virus groups having members which are considered a significant biosecurity threat to the industry

- an invitation, including a survey form, seeking comment or information on the topic. The response was not high but personal contact from team members gained an insight into industry needs and ideas on future investment.

- key recommendations for future RD&E investment on virus disease management in the industry.

These outputs will be widely circulated to the industry through websites and industry publications. The recommendations can also be discussed with SIAPs. Members of the project team are also contributing to the vegetable industry biosecurity plan to provide specialist advice on viral incursion threats.

Recommendations

- The key areas for future investment for more effective virus disease management in vegetable crops are gaining a better understanding of:
    - genetic variability of viruses
    - disease resistance mechanisms
    - vector diversity and dynamics
    - product quality
- The virus groups with highest priority for future investment are the tospoviruses (Tomato spotted wilt virus) and the potyviruses, particularly those infecting cucurbits

- Future investment in the biology and management of the major virus vectors, aphids, thrips and whitefly

- Research and development should use the principles of area wide management of viruses and vectors in both field and protected cropping situations

- Extension methodology for enhancing the adoption of area wide management be investigated in a specific project

- The key virology diagnostic laboratories develop more targeted collaboration to better service the vegetable industry

- Investment in the revision of the VIDE database be supported to provide current, accurate data on the presence, distribution and importance of plant viruses in Australia.

- The provision of targeted, timely information on viruses and their management to the vegetable industry continue to be a high priority

- Linkages across industries and RDCs be encouraged where the biology of the virus and vector would make collaborative work and delivery of outcomes more cost effective, efficient and meaningful

- The role of seed as a pathway for virus incursions be investigated

Intellectual property/commercialization

No commercial IP generated

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Appendices:

1. Literature review on viruses of national importance to the vegetable industry
2. Overview of diagnostics for detection and identification of plant viruses in Australia
3. Summary of workshop discussions May 2016
4. Industry survey form
5. Key recommendations for future investment in RD&E

Appendix 1: Literature review

The Australian vegetable industry produced 3.15 million tonnes of produce in 2014/15, valued at $3.53B (HORT INNOVATION 2016). Table 1 provides production figures and values for major vegetable crops. The industries within the vegetable sector can be grouped as follows:

- Leafy and Asian vegetables
- Brassica vegetables
- Cucurbit vegetables including melons
- Tomato and capsicum
- Sweet corn, asparagus, beans and peas
- Fresh and processing potatoes
- Carrots and onions

The categories narrow if only crops paying the vegetable levy are considered: beetroot, carrots, celery, parsnips, beans, peas, lettuce, vegetable brassicas, vegetable cucurbits, sweet corn, sweetpotato, capsicum, eggplant, chilli and leeks.

Although this review will focus on crops within the vegetable levy system, all vegetables need to be considered to some extent because of botanical relationships, virus and vector host ranges and the relationships of cropping systems, particularly with increasing interest in area wide management of vegetable diseases.

Crop protection has always been a significant component of profitable vegetable production and the impact of virus diseases has been an important issue over many years in several sectors of the industry. Virus diseases are generally difficult to manage as many viruses have active insect vectors facilitating rapid spread, plants cannot be cured once infected hence management needs to be aimed at preventing or reducing infection and resistant varieties are often not available to protect against important viral pathogens.

Table 1 Production and value of Australian vegetable crops 2014/15. Data for this table was obtained from Australian Horticultural Statistics Handbook 2016 and based on that collated for 2014/15

Crop	Production(t)	Value of production ($m)	Production by States (%)	Production by region
Fresh beans	29 931	74.2	QLD 79 VIC 15	Bowen, Bundaberg, SE QLD Gippsland
Brassicas				
Broccoli	68 571	188.7	VIC 48 QLD 27 WA 11	Robinvale, Melbourne Lockyer Valley, Stanthorpe Perth Metro
Cabbage	67 463	44.1	QLD 24 VIC 30 NSW 21 WA 17	Lockyer Valley Melbourne metro Sydney region Perth region
Cauliflower	63 510	49	VIC 27 QLD 26 WA 15 NSW 15	Werribee Lockyer Valley Perth metro Sydney metro
Capsicum	71 634	144.7	QLD 78 WA 7	Bowen, Bundaberg Carnarvon
Carrots	291 600	190.4	WA 34 VIC 19 TAS 18 SA 16 QLD 11	Gingin, Preston East Gippsland Forth Riverland South East
Celery	59 484	50.2	VIC 58 QLD 24 WA 14	Dandenong Granite Belt Perth metro
Cucurbits				
Cucumber	84 693	183.5	SA 44 QLD 38	Riverland, Adelaide Bundaberg, SE
Pumpkins	117 994	58	QLD 44 NSW 36 WA 7	Bundaberg, Darling Downs MIA
Zucchini	34 907	62	QLD 47 VIC 26 NSW 19	Bowen, Bundaberg Sunraysia Bathurst
Melons				
Watermelon	151 927	116.3	QLD 35 NSW 29 NT 21 WA 8	Bundaberg, Bowen, Chinchilla Riverina Katherine

Crop	Production(t)	Value of production ($m)	Production by States (%)	Production by region
Muskmelon (rockmelon, honeydew)	65 281	69.5	QLD 35 NSW 29 NT 20 WA 9	Kununurra Bowen, Bundaberg Riverina Darwin Perth
Eggplant	8 669	16.2	QLD 51 NSW 22 VIC 11	Bowen/Burdekin Sydney Goulburn valley
Fresh herbs (fennel, parsley and others)	11 380	121	VIC 80 (fennel) QLD 46 } VIC 30 } NSW 19 }	Werribee Parsley – several locations
Garlic	1 872	7.5	VIC 67 NSW 21	
Lettuce (Head)	122 675	131.2	QLD 35 VIC 32 WA 16 NSW 10	Lockyer Valley/Darling Downs Gippsland Perth metro Sydney basin
Leafy salad vegetables	54 579	315.3	VIC 45 QLD 28 TAS 10	
Leafy Asian vegetables	27 176	62.5	NSW 43 QLD 28 VIC 24	Sydney basin Gympie Melbourne area
Parsnips	3 322	9.2	VIC 43 WA 26 TAS 11	Melbourne metro Perth Metro North West
Peas (Fresh)	20 674	42	VIC 46 QLD 39	Goulburn valley Bundaberg/Lockyer Valley
Sweet corn (Fresh)	62 019	66.7	QLD 39 NSW 26 VIC 22	Bowen/Burdekin, Lockyer Valley Riverina, Sydney basin Gippsland
Sweetpotato	55 191	64.6	QLD 76 NSW 19	Bundaberg, Atherton Tablelands Northern NSW
Tomatoes	411 217	548	QLD 39 NSW 32 VIC 10 WA 10 SA 8	Bowen, Bundaberg, Stanthorpe

Among the first virus diseases to affect Australian vegetable crops were those caused by *Tomato spotted wilt virus* (TSWV) which was first described from tomato in Victoria (Brittlebank1919). The virus caused serious losses in all

Australian States during the 1920s and 1930s, particularly in tomato crops (Samual 1930). Severe epidemics also occurred in potato crops in NSW and Victoria in 1945-46 and 1946-47 with disease levels of up to 60% and the rejection of 31% of crops examined for seed certification in NSW (Norris 1951).

TSWV remains one of the most widespread and damaging viruses in Australia. The incidence of TSWV in vegetable crops began to increase in the 1990s and continued to do so into the 21st century (Latham and Jones 1996; Wilson 1998; Persley et al. 2006). A significant factor in resurgence of the pathogen was the entry into Australia of the western flowers thrips (*Frankliniella occidentalis*) in 1993, a proven efficient vector of TSWV.

Several other important vegetable crops had significant virus disease problems in the years leading up to 2000.

Carrots were severely affected by motley dwarf disease in Victoria and other States in the 1940s and 50s, particularly varieties derived from Chantenay stock. Crops frequently had a high percentage of plants that were stunted with mottled, distorted foliage and poor root development (Stubbs 1948; 1952). The disease was later shown to be due to infection by two viruses, the luteovirus *Carrot red leaf virus* and the umbravirus *Carrot mottle virus*, both of which were transmitted by the aphid *Cavariella aegopodii* in a persistent manner (Murant 1974, Waterhouse and Murant 1982). By the mid -1960s the disease had been well controlled through the selection of virus tolerant or aphid repellent varieties, a change in sowing dates to avoid seasonal flushes of the carrot aphid, the widespread use of insecticides on carrots and the effectiveness of an introduced parasite on the carrot aphid (Buchen-Osmond et al. 1988).

Aphid –transmitted potyviruses have caused sporadic epidemics in celery over several decades. Alberts et al (1989) reported a severe outbreak of *Celery mosaic virus* around Adelaide during 1986/87 where up to 70 % of plants in crops were affected, resulting in yield losses and downgrading of produce. *Celery mosaic virus*, sometimes in combination with *Cucumber mosaic virus*, caused extensive losses on the Mornington peninsula in Victoria in the late 1990s. This prompted an examination of potyviruses infecting Apiaceae in Australia (Moran et al.2002) and three distinct viruses were identified by gene sequencing: *Celery mosaic virus* from celery, *Carrot virus Y* from carrot and *Apium virus Y* infecting parsley, sea celery and several weedy species of Apiaceae. *Carrot virus Y* was subsequently found in six States and, as with *Celery mosaic virus*, was more likely to be damaging when carrot or celery crops where grown throughout the year (Latham et al. 2004, Latham and Jones 2004).

Lettuce crops have been severely damaged by virus diseases for many decades in all States. Although TSWV and *Cucumber mosaic virus* caused sporadic losses, epidemics of *Lettuce mosaic virus* (LMV) and *Lettuce necrotic yellows virus* (LNYV) were the most frequent cause of crop failures (Stubbs and Grogan 1963). The symptoms of TSWV, LMV and LNYV are very similar in lettuce and detailed work by Stubbs and Grogan (1963) demonstrated that LNYV was a previously undescribed virus transmitted persistently by the sowthistle aphid (*Hyperomyzus lactucae*) and having Sowthistle (*Sonchus oleraceus)* as the major alternative host of both the virus and vector. Stubbs et al. (1963) also found that destruction of Sowthistle in and around lettuce crops was an effective means of managing the disease.

Bean summer death disease caused by the geminivirus *Tobacco yellow dwarf virus* caused major losses in susceptible bean cultivars, particularly in areas west of the Great Divide after periods of hot dry weather favoured the migration of the leafhopper vector *Orosius orientalis* from alternative hosts into bean crops (Ballantyne 1968; Thomas and Bowyer 1984).

Vegetable cucurbit and melon crops in northern Australia have frequently developed high levels of virus disease since at least the 1960s. *Watermelon mosaic virus* (WMV) was the dominant virus until about 1970 (Greber 1969) when *Papaya ringspot virus*-type W was detected and caused considerable damage to watermelon and pumpkin crops (Greber 1978). The economic impact of viruses on cucurbit production increased further when *Zucchini yellow mosaic virus* was found in 1987 (Greber et al 1988).

Despite periodic outbreaks of TSWV and *Tomato mosaic virus*, the most prevalent and damaging virus in tomato and capsicum crops in Queensland for some 40 years was *Potato virus Y* (Sturgess 1956; Thomas et al 1989). The virus occurred in all production areas and surveys frequently revealed incidences of 50% to 100% in both tomato and capsicum. Several strains virulent towards resistance sources in capsicum were also identified (Thomas et al. 1989).

The Australian vegetable industry has undergone significant change over the last 20 years including consolidation of production with a relatively small group of growers producing a large volume of produce, often at several locations to allow continuity of production; an increase in the area of protected cropping for several crops including capsicum, tomato, leafy greens, cucumber and lettuce; greater emphasis on minimising pesticide use and using principles of integrated pest and disease management to protect crops.

Although the suite of viruses causing losses may have changed virus diseases and their management remain a challenge for the industry.

The viruses of current and potential importance to the industry are discussed below. A summary of the viruses and hosts is listed in Table 2.

Plant viruses

Plant viruses are assigned to families, several of which have viruses of current or potential importance to the industry. These families/ viruses are discussed below

Potyviridae

The family Potyviridae comprises six genera *Bymovirus, Ipomovirus, Macluravirus, Potyvirus, Rymovirus and Tritimovirus.* The two genera of concern to the vegetable industry are the Ipomoviruses and particularly the Potyviruses.

The Ipomoviruses, from Ipomoea, sweetpotato, have Sweet potato mild mottle virus (SPMMV) as the type species and five species and one probable species are currently recognised (Webb et al. 2016; Desbiez et al. 2016). Members of the group are transmitted in a semi-persistent mode by *Bemisia tabaci* and by vegetative propagation. SPMMV has not been detected in Australia but is listed as a biosecurity threat to the industry.

The genus Potyvirus with Potato Virus Y as the type species has over 150 recognised members, making it the most prevalent and economically important group of plant viruses worldwide. Virions are flexuous filaments 650-900 x 11-15nm with a single stranded, positive sense RNA genome of approximately 9.7 kb (King et al. 2012).

Potyviruses are transmitted by numerous aphid species in a non- persistent manner. With this mode of transmission aphids can both acquire and transmit a virus in feeding times of 30 seconds or less. Aphid transmission requires a helper component (HC-Pro). While aphid species differ considerably in their efficiency to transmit a particular potyvirus, there is little vector specificity. Common and efficient vectors of many potyviruses include *Myzus persicae* and *Aphis gossypii*.

Seed transmission of several potyviruses is well established, e.g. Lettuce mosaic virus, Pea seed-borne mosaic virus while very low rates of seed transmission have been reported or are suspected for a significant number of other potyviruses allowing a pathway for long distance dispersal.

Potyviruses are mechanically transmissible under experimental conditions and in at least some instances, under field conditions through wounding and abrasion (Coutts et al. 2013; Coutts and Jones 2015).

The most damaging of the potyviruses affecting vegetable crops in Australia are the three that infect cucurbits :- Papaya ringspot virus- type W (PRSV-W), Watermelon mosaic virus (WMV) and Zucchini yellow mosaic virus (ZYMV) (Coutts and Jones 2005: Persley 2011). The distribution and importance of these viruses differs between States (Coutts and Jones 2005; Persley 2011).

Papaya ringspot virus is widespread and dominant in cucurbit crops in Queensland, particularly in the major production areas at Bundaberg, Bowen, Burdekin, Lockyer valley and Chinchilla. Significant losses occur in at least some areas each year in zucchini, squash, pumpkin and melons. Losses occur through reduced yields and culling and downgrading through fruit distortion and mottling. Epidemics are characterised by rapid virus spread by aphids with very high infection levels developing at or before flowering which often results in almost total crop loss in watermelons and zucchini.

Although PRSV has been recorded in cucurbits in Western Australia, it is Zucchini yellow mosaic virus that dominates in Kununurra, Carnarvon and Perth. Losses are frequently high in all districts, particularly in melons, squash and zucchini (Coutts et al. 2011).

Watermelon mosaic virus occurs in all districts and does not affect yield and quality as much as PRSV and ZYMV. However, in surveys over three years at Swan Hill Victoria WMV was the only virus detected in zucchini crops which had conspicuous mosaic symptoms with fruit mottling and some distortion (Rodoni 2011).

Management of potyviruses in cucurbits is difficult because insecticides are of little value in controlling non –persistent aphid transmitted viruses, inoculum is generally available throughout the year in various cucurbit sources and resistant varieties are not available in most commercial cucurbits. A few virus resistant pumpkin varieties are available and zucchini varieties with tolerance to potyviruses are now grown in most districts, although these are vulnerable to more severe virus strains as has been demonstrated with an aggressive strain of ZYMV present in Kununurra WA (Coutts et al. 2011).

Tospoviruses

The genus *Tospovirus* is one of five genera in the family *Bunyaviridae* but the only one containing plant pathogens. Tospoviruses are among the most widespread and damaging of plant viruses, causing major losses in a broad range of food and ornamental crops throughout the world, both in field-grown crops and glasshouse growing situation (Pappu et al. 2009). The genus name Tospovirus is derived from the type species, Tomato spotted wilt virus which was first found and described from Australia (Brittlebank 1919).

Tospovirus genomes comprise one negative-sense large (L) and two ambisense medium (M) and small (S) single-stranded RNAs. Virus particles are spherical or pleomorphic, 80-120nm in diameter and have a lipid envelope with glycoprotein projections (Kormelink 2011)

All tospoviruses are transmitted in a persistent by thrips (*Thysanoptera*) in the genera *Frankliniella*, *Thrips*, *Ceratothripoides* and *Scirtothrips*. Only the first and early second instar larvae are able to acquire and then transmit tospoviruses as adults. Tospovirues generally have broad host ranges, develop a wide range of symptoms and have a considerable capacity to generate genetic variability through mutation and genome re-assortment.

The international dispersal of the efficient tospovirus vector western flower thrips (*Frankliniella occidentalis*) has been a major factor in the increased importance of tospoviruses worldwide (Gilbertson et al. 2015) This species was first reported from Australia in 1993 (Malipatil et al. 1993).

Of the 29 recognised and proposed species of tospoviruses, three are known to occur in Australia:- Tomato spotted wilt virus (TSWV), Capsicum chlorosis virus (CaCV) and Iris yellow spot virus(IYSV)(Persley et al. 2006).

TSWV is very widely distributed in Australia in weed, crop and amenity hosts. Sporadic outbreaks can occur in a range of hosts with capsicum, tomato and lettuce being the crops most frequently affected (Persley et al. 2006). Recent significant outbreaks include tomato crops at Bowen in 2014/15, capsicum at Carnarvon in 2015 and capsicum in protected cropping at Virginia SA in 2015/16. The best documented situation with TSWV is from vegetable crops under protected cropping at Virginia north of Adelaide. The virus was estimated to have caused crop losses in capsicums, tomato and lettuce of some $70m in 2000 following several severe epidemics related to the inability to control high populations of western flower thrips.

TSWV remains the most significant problem for capsicum growers in Virginia. Resistance to TSWV in capsicums became ineffective soon after the release of resistant varieties in the early 2000s (Sharman and Persley 2005) and losses from the virus and thrips damage were so high in 2011 that the continued existence of the industry was threatened. There were control failures with all insecticides used resulting in losses of at least several million dollars from virus and insect/ mite damage.

An IPM program was implemented by a commercial company and received good support from growers. As of 2017 the program remains in place and has achieved good results. However, TSWV remains a significant issue in capsicum production and requires further work to develop effective resistance to TSWV and greater effort to have a resilient, cost effective IPM program.

Capsicum chlorosis virus (CaCV) was first described from capsicum and tomato in Queensland in 1999 (McMichael et al. 2002). It is a member of the Watermelon silver mottle virus or serogroup IV group of tospoviruses, which are dominant in south- east Asia. Based on survey data and archived samples the virus most likely entered Queensland in recent times. It is vectored by both *Thrips palmi* and the tomato thrips *Frankliniella schultzei* (Persley et al. 2006).

CaCV occurs in both north and south Queensland where there have been sporadic severe outbreaks in both capsicum and tomato. It is well established at Bundaberg in a major alternative host *Ageratum conyzoides*. Considerable work has been undertaken to introduce CaCV resistance from a resistant *Capsicum chinense* accession into commercial cultivars (Persley et al. 2006; McGrath et al. 2016). Recent work has also elucidated aspects of the molecular mechanisms governing the resistance response to CaCV in capsicum (Widana Gamage et al. 2016).

Iris yellow spot virus (IYSV) is transmitted by *Thrips tabaci* and has been recorded in all States in onion and other Allium species (Coutts et al. 2003).

Tobamoviruses

There are 35 species of in the *Tobamovirus* genus (Family *Virgaviridae*) with Tobacco mosaic virus being the type species. Other members include Tomato mosaic virus (ToMV), Cucumber green mottle mosaic virus (CGMMV) and Pepper mild mottle virus (PMMV).

All tobamoviruses are easily transmitted by mechanical means, by contact between plants and are often carried on seed. Few have specific insect vectors and survive for long periods (months, years in soil, debris and can be spread through contaminated water.

CGMMV was first detected from field grown watermelons in the NT in 2014 (Tesoriero et al. 2015) and is currently (March 2017) known to occur at several locations in WA and in greenhouse cucumber crops at Bundaberg QLD. The virus is seed borne in several cucurbit species, infects most cultivated cucurbit species and can also infect a range of weed species, including several outside of Cucurbitaceae (Shargil et al. 2016). Despite mandatory testing of all cucurbit seed for planting at the Australian border further outbreaks are likely and the characteristics of the virus make eradication/ management difficult (Li et al. 2015). The virus strain present in Australia is very closely related to published viral sequences from Canada, Israel and India (Kehoe et al. 2017).

While tobamoviruses are generally well managed in capsicum and tomato through resistance (Kenyon et al. 2014), specific local issues may occur. One such case is ToMV in greenhouse capsicum crops in Virginia SA where the virus has been steadily moving through crops since about 2010 with considerable economic loss through unmarketable fruit. There is reluctance on the part of many growers to change the main variety grown because of market acceptability, yield and shelf life. Management of this contact transmitted virus in a closely settled, labour intensive situation is proving difficult.

Begomoviruses

Begomoviruses are one of four genera in the family *Geminiviridae*. All geminiviruses are insect –transmitted with circular, single-stranded (ss) DNA genomes encapsidated in twinned icosahedral particles. The begomoviruses are the most numerous of the geminiviruses and occur widely in the tropics, sub tropics and some temperate zones. All are transmitted by cryptic species in the *Bemisa tabaci* complex in a persistent and circulative manner (Brown, 2007).

The marked global dispersal and diversification of begomoviruses over the last 20 years can be attributed to several factors including movement of viruses and vectors via trade and horticultural produce, the capacity of begomoviruses to rapidly evolve by mutation and recombination and the association with subviral components, e.g. satellite DNAs which can alter host range and virulence (Mansoor et al. 2006; Gilbertson et al. 2015. Important hosts of begomoviruses include cassava, cotton and the vegetables tomato, capsicum, legumes, sweetpotato, cucurbits and potato. Begomoviruses cause enormous crop losses worldwide, for example $US 300 million per annum to grain legumes in India and US$140 million in tomato in Florida from Tomato yellow leaf curl virus (Varma et al. 2011). The estimated losses in cotton from Cotton leaf curl virus in Pakistan from 1992 to 1997 were estimated at $US 5billion (Varma et al. 2011).

Few begomoviruses have been recorded in Australia. Tomato leaf curl virus has been present in northern Australia for many decades and is probably endemic and is transmitted by the Australian indigenous cryptic species of *Bemisa tabaci* (Stonor et al. 2003). In 2006 Tomato yellow leaf curl virus was found in south Queensland (Van Brunschot et al. 2010). The virus is now widespread and damaging in all major production areas in Queensland with resistant hybrids being essential for economic production (Campbell et al. in press).

Begomoviruses are a major threat to the northern Australia vegetable industry. The whitefly vector is abundant and widespread. The recent entry of TYLCV demonstrated a pathway which is potentially available to the very large number of begomoviruses present to our north through all of south- east Asia and beyond.

Criniviruses

The genus *Crinivirus* is one of the three genera in the family *Closterovirdae* and includes viruses with segmented genomes, transmitted by whiteflies (Tzanetakis et al. 2013). Crinivirus transmission is species specific and performed exclusively by whiteflies in the genera *Trialeurodes* and *Bemisia* in a semi-persistent manner. Criniviruses often cause symptoms which can be readily mistaken for physiological or nutritional disorders. The only crinivirus currently recognised in Australia is Beet pseudo-yellows virus, first reported from Tasmania in 1981 (Duffus and Johnstone 1981) and the cause of cucumber yellows which is common in greenhouse cucumber crops in Virginia (Persley et al. 2012). As is typical of many diseases caused by crinivirus, symptoms first appear on the older leaves and progress towards the apex. Symptoms include interveinal yellowing, brittle leaves, inward curling of leaves and early senescence (Persley et al. 2011). The extent of yield loss in cucumber crops is not known but loss of photosynthetic activity, early senescence and predisposition to two spotted mite and powdery mildew must affect crop performance.

Criniviruses are an emerging problem worldwide and viruses such as Cucurbit yellow stunting disorder virus, Tomato infectious chlorosis virus and Sweet potato chlorotic stunt virus have considerably expanded their geographic distribution in recent years and are real threat to the Australian vegetable industry (Tzanetakis et al.2013).

Ophioviruses

Lettuce big vein disease is common in the crop in many countries, including Australia and has been present for decades (Maccarone 2013). It is now generally accepted that the Ophiovirus, Mirafiori lettuce big vein virus is the causal agent of the disease, rather than Lettuce big vein associated virus (lot et al 2002; Maccarone 2013). Both viruses are transmitted by the soil borne fungus *Olpidium virulentus* (Maccarone 2013; Rochon 2016).

In eastern Australia, Gambley (2011) investigated the distribution of the two viruses, the molecular variation of several isolates of MLBVV and symptom variation between isolates. It was recommended that further work be undertaken on survival of the fungal vector in the soil and hydroponic systems and the effect of disease on lettuce shelf life and production be more thoroughly investigated.

The Ophiovirus Ranunculus white mottle virus was identified as the cause of capsicum vein yellows disease in greenhouse crops in Virginia (Gambley and Persley, unpublished; Persley et al. 2011). The disease is now widespread in the district but the effects on production are not known, although these do not appear to be major.

Cucumber mosaic virus

Cucumber mosaic virus (CMV) is one of the most common plant viruses worldwide with an extremely wide host range (Hema et al.2015). However, it is of relatively minor importance in the Australian vegetable industry. CMV has been found in celery, sometimes in association with Celery mosaic virus, lettuce and occasionally in cucurbits. The most significant current issue is in field grown capsicums in Carnarvon WA where the virus has caused significant yield losses, often in association with TSWV, for several years. No suitable resistant varieties are available and old, infected capsicum crops appear to be an important inoculum source (Persley 2014; Coutts 2012). Further work on the epidemiology of the virus in this isolated production area seems warranted.

Tomato torrado virus

Torradoviruses are an example of a group of recently discovered viruses. Tomato torrado virus (ToTV), the type member of the genus *Torradovirus* was first described in 2007. There are now nine recognised species (van der Vlugt2015), several of which infect tomato. ToTV was identified from tomato crops in Virginia in 2010 (Gambley et al. 2010), although the disease had been present for some years prior to accurate identification. Tomato hybrids vary in reaction to the virus and torrado tolerance is now a selection criterion for tomato hybrids grown in Virginia. The virus can also infect capsicum and eggplant

ToTV was subsequently found in greenhouse tomato crops at Lara in Victoria in 2010.

The virus is efficiently transmitted by both the greenhouse and silverleaf whitefly, has several weed hosts and is a threat to both greenhouse and open field solanaceous crops in Australia.

Cowpea mild mottle virus

In March 2016 a disease causing leaf mottling and pod discolouration of French bean grown for the fresh market was found in the Fassifern area of south- east Queensland. The high incidence of the virus disease resulted in several crops not been harvested and considerable losses from a high percentage of distorted and discoloured pods in harvested crops. Losses were estimated at approximately $4000 000 over several months in 2016. The pathogen responsible was identified as Cowpea mild mottle virus (Persley, unpublished data).

CPMMV is a Carlavirus and is a member of a sub group of Carlaviruses which are transmitted by *Bemisia tabaci* and serologically unrelated to 20 or more aphid transmitted members of the genus (Brunt 2016). The natural host range of CPMMV is largely confined to species within *Fabaceae* with bean, soybean, cowpea, peanut and mung bean the economic species most frequently affected (Brunt2016).

The wide distribution of CPMMV in Africa, Asia, South America and Oceania strongly suggests that the movement of infected seed is a significant pathway for virus dispersal. The detection of the virus in bean in 2016 is the first detection of the virus in Australia and of Carlavirus infection of *Fabaceae* species in Australia.

Further studies are continuing on the epidemiology, genetic diversity, transmission and management of the virus in Australia.

Table 2 A summary of important viruses present in Australia and their vegetable host crop(s)

Crop/Family	Virus	Means of spread
Bean (Fabaceae)	Bean common mosaic virus (BCMV)	Seed, aphids (non-persistent)
	Bean yellow mosaic virus (BYMV)	Aphids (non-persistent)
	Subterranean clover stunt virus (SCSV)	Aphids (persistent)
	Tobacco yellow dwarf virus (TYDV) (Bean summer death disease)	Leafhopper (*Orosius orientalis*), (persistent)
	Cowpea mild mottle virus	Seed; Silver leaf whitefly
Brassicas (Brassicaciae)	Beet western yellows virus (BWYV)	Aphids (persistent)
	Turnip mosaic virus (TuMV)	Aphids (non-persistent)
Capsicum (Solanaceae)	Capsicum chlorosis virus (CaCV)	Thrips (persistent)
	Cucumber mosaic virus (CMV)	Aphids (non-persistent)
	Pepper mild mottle virus (PMMV)	Seed, contact
	Potato virus Y (PVY)	Aphids (non-persistent)
	Tomato spotted wilt virus (TSWV)	Thrips (persistent)
Carrot (Apiaceae)	Carrot virus Y (CaVY)	Aphids (non-persistent)
Celery (Apiaceae)	Celery mosaic virus (CeMV)	Aphids (non-persistent)
Cucurbits (Cucurbitaceae)	Cucumber mosaic virus (CMV)	Aphids (non-persistent)
	Cucumber green mottle mosaic virus	Seed; contact
	Papaya ringspot virus – type W (PRSV-W)	Aphids (non-persistent)
	Squash mosaic virus (SqMV)	Seed ,beetle Aphids (non-persistent)
	Watermelon mosaic virus (WMV)	

Crop/Family	Virus	Means of spread
	Zucchini yellow mosaic virus (ZYMV)	
Eggplant (Solanaceae)	Tomato spotted wilt virus (TSWV)	Thrips (persistent)
Lettuce (Asteraceae)	Cucumber mosaic virus (CMV)	Aphids (non-persistent)
	Lettuce mosaic virus (LMV)	Lettuce seed, aphids (non-persistent)
	Lettuce mirafiori virus/Lettuce big vein virus (Lettuce big vein disease)	Soil-borne fungus *Olpidium*; infested transplants, contaminated soil and hydroponic systems
	Lettuce necrotic yellows virus (LNYV)	Aphids (persistent)
	Tomato spotted wilt virus (TSWV)	Thrips (persistent)
	Turnip mosaic virus (TuMV)	Aphids (non-persistent)
Onion and related species (Alliaaceae)	Iris yellow spot virus (IYSV)	Thrips (*Thrips tabaci*), (persistent)
	Onion yellow dwarf; Leek yellow stripe virus (OYDV; LYSV)	Aphids (non-persistent), infected garlic cloves and onion bulbs
Pea (Fabaceae)	Pea seed-borne mosaic virus (PSbMV)	Pea seed, aphids (non-persistent)
	Subterranean clover stunt virus (SCSV)	Aphids (persistent)
Potato (Solanaceae)	Potato leafroll virus (PLRV)	1 Aphids (persistent); infected tubers
	Potato virus X (PVX)	Contact; infected tubers
	Potato virus Y (PVY)	Aphids (non-persistent); infected tubers
	Potato virus S (PVS)	Aphids (non-persistent); contact; infected tubers
	Tomato spotted wilt virus (TSWV)	Thrips; infected tubers
Sweet corn (Poaceae)	Johnson grass mosaic virus (JGMV)	Aphids (non-persistent)
Sweetpotato (Convolvolaceae)	Sweet potato feathery mottle virus (SPFMV)	Aphids (non-persistent)
Tomato	Capsicum chlorosis virus (CaCV)	Thrips (persistent)

Crop/Family	Virus	Means of spread
(Solanaceae)	Cucumber mosaic virus (CMV)	Aphids (non-persistent)
	Potato virus Y (PVY)	Aphids (non-persistent)
	Tomato spotted wilt virus (TSWV)	Thrips (persistent)
	Tomato mosaic virus (TMV)	Contaminated seed, contact, contaminated equipment, tomato crop debris
	Tomato torrado virus	Greenhouse and silverleaf whitefly
	Tomato leaf curl virus (Australia) (TLCV) and Tomato yellow leaf curl virus (TYLCV)	Whitefly (Bemisia species)
	Potato leafroll virus (Tomato yellow top virus) (PLRV)	Aphids (persistent)

Virus management

Management of virus diseases is largely defined by the principles of:

- Exclusion/ avoidance
- Reduction in virus inoculum levels
- Protection of the host.

Efforts to develop, refine and apply these principles to viruses infecting vegetables in Australia have been undertaken for many years and have received considerable support from the vegetable industry. Examples can be found in Jones (2004); Coutts et al. 2013; Coutts et al. 2011; Coutts and Jones 2005; Sharman and Persley 2005; Persley et al. 2006; Latham and Jones 2004).

Considerable work on integrated viral disease management across a range of crops is reported in Persley (2011) and Persley (2014). The results and recommendations from this work has been provided to the vegetable industry in, for example, Persley et al. (2011); Persley and Gambley 2009; Persley and Gambley 2010 a,b,c.; Persley 2007; Coutts et al. 2012).

Future work will continue to develop and adapt management systems to reduce the economic impact of virus diseases. Where appropriate area wide management strategies should be encouraged to manage both vectors and viruses.

New technologies should be assessed and applied where appropriate to, for example, provide more durable resistance against viruses which have proven difficult to manage with conventional resistance and management systems (Borges and Martienssen 2015; Mitter et al. 2017).

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Appendix 2: Overview of diagnostics for detection and identification of plant viruses in Australia

Fiona Constable and Denis Persley

Accurate diagnosis of the cause of a plant virus disease is an essential step in determining the properties of the virus, how it is transmitted and designing management methods to reduce the incidence and economic impact.

Awareness of possible symptoms associated to diseases is often critical in making a rapid diagnosis of a virus associated disease. However, symptoms are often confused with other abiotic and biotic conditions that mask or confound symptoms based diagnosis of virus infection. Different viruses, with different epidemiology and management strategies may cause the similar symptoms. Some important viruses may be symptomless depending upon the plant host species or variety infected or due to environmental conditions and these can pose a risk to production of more susceptible hosts planted nearby or should environmental conditions change. Therefore symptoms alone may not be good indicators of virus disease and an accurate method of diagnosis is required.

A critical and sometimes neglected area of disease diagnosis is the collection of representative samples and good information on symptoms, disease incidence, field distribution,varieties affected, observations of possible insect vectors, movement of equipment and people within the crop, and weather conditions. Some of this information can be particularly lacking with suspected virus diseases as growers, consultants and others are often not aware of the range of viruses that can infect a crop and how the epidemiology can differ considerably between viruses leading to different control methods being necessary for effective management. But this information can be critical in assisting a diagnostician to target a specific virus or viruses and provide an accurate and rapid diagnosis.

Sampling appropriate tissue types and volumes of samples to assist active diagnostic testing is required. Adequate sampling in the face of a symptomless or asymptomatic virus infection is required for accurate diagnosis and estimating incidence of disease in a crop and subsequent risk to the development of the crop and other susceptible crops nearby. In this instance it may be necessary to apply a statistical basis to sampling to estimate virus incidence. Samples should always be in the best possible condition and forwarded as quickly as possible to assist the reliability and sensitivity of the diagnostic test, degraded samples can result in false negative results, if they can be tested at all.

Diagnostic methods need to be sensitive, reliable, reasonably rapid, repeatable and cost-effective, depending on their purpose. Rapid laboratory or field-based diagnostics can assist in early control to prevent further spread, even before disease is observed.

Diagnostic tests for plant viruses can be broadly divided into:

1) Biological testing using test species which are sensitive to a particular virus and display characteristic symptoms. These tests are often labor intensive and may take at least several weeks to obtain results. Virus strains and mixed virus infections can lead to different symptom expression on an indicator and complicate interpretation. Symptomless infections occur.

2) Electron microscopy which allows virus particles to be seen with a transmission electron microscope. This method is of most value with high concentration viruses and those which have filamentous particles and are more easily visualised. Electron microscopes are expensive to purchase and maintain and are generally located only in large central laboratory facilities.

3) Serology which targets the viral proteins and is based on the specific interactions of pathogen proteins and antibodies raised against them.

Modern plant virus diagnostics largely began with the introduction of the serological test ELISA (Enzyme Linked

Immunosorbent Assay) in the mid-1970s (Clark and Adams (1977). This assay, adapted from medical diagnostics, revolutionised virus diagnosis by simplifying diagnosis and shortening the time to reach conclusive results. ELISA quickly became widely accepted by plant virology laboratories worldwide and many improvements were introduced, including the development of monoclonal antibodies which improved assay sensitivity and specificity (Boonham et al. 2014).

ELISA remains a major diagnostic tool in plant virology because it is cost effective, robust, easy to use and can be scaled to test large numbers of samples in breeding or certification programs (Torrance and Jones 1981). A key aspect of the success of ELISA has been the commercial availability of reagents, equipment and a broad range of antibodies to allow testing to be done in a wide range of locations with minimal experience needed to undertake routine work. Further developments of serological techniques have included the development of lateral flow or “dipstick” technology which are rapid and field deployable and can be as sensitive as ELISA based techniques (Albersio et al. 2012).

ELISA and lateral flow technology requires access to high quality antisera, the production of which is a lengthy and expensive process which is not always successful, especially for viruses or their epitopes that are difficult to isolate or due to cross reactivity with other viruses or non-viral proteins.

Serological methods are not always sensitive enough to detect viruses in low concentrations in plants or detect strain differences within a virus species. Cross reactivity of the anti-sera viruses

4) Nucleic acid based detection targets the viral nucleic acid (DNA or RNA) which carries the genetic information of the virus.

To overcome these potential issues and broaden diagnostic capability diagnostic methods targeting the viral nucleic acid have seen a rapid development over the last 15 years (Boonham et al 2014). These tests are based on the Polymerase Chain Reaction (PCR) which multiplies very large amounts of a viral sequence thus providing much higher sensitivity than can be obtained with ELISA and other serological methods.

PCR can be highly specific, detecting the gene of a particular virus species or strain, and it can be universal so that groups of viruses, such a genus or family, can be detected (Zheng et al 2010). However the development of universal tests, which are likely to detect most species or strains in a virus group, requires sufficient sequence information of the group to ensure all members can be detected. A positive conventional PCR test, in which the PCR amplification product is visualized using separation by agarose gel electrophoresis, staining with a dye and that fluoresces under UV illumination, can be sequenced for confirmation if required. Real-time (quantitative) PCR (qPCR) techniques have been developed that simultaneously amplify and measure the presence of the target in a PCR reaction, without laboratory processing post PCR, and these can be used to measure the amount of virus present in a sample (Van Guilder et al 2008).

PCR is frequently a laboratory embedded method which requires specialized equipment and technical skill to prepare, run and interpret the test result. However it is a method that lends itself, like ELISA, to high throughput screening and some platforms are able to run the same PCR test on more than 300 samples at one time. The bottle neck for PCR can be sample preparation, which may be more complex than ELISA. It can be dependent on the production of quality nucleic acid, which is often produced by commercially available nucleic acid extraction kits, which can be expensive.

Loop-mediated isothermal amplification (LAMP) and recombinase polymerase amplification (RPA) assays are field-deployable molecular tests that also multiply very large amounts of a viral sequence (Boonham et al 2014; Mekuria et al 2014). They are simple, rapid, specific, cost-effective and can detect viruses more quickly than PCR procedures, yet have a similar sensitivity. They don’t require complex sample preparation and can be used on crude plant homogenates and require less technical skill for interpretation. If the LAMP or RPA tests are being monitored electronically in real-time using the portable monitors then they are not amenable to high throughput as only 6-12 samples can be handled at any one time. However if the LAMP or RPA reaction is to be measured visually with a change in turbidity or colour, the test is not limited to these numbers as a portable incubator maintaining the appropriate single temperature can hold a larger number of tubes. High sample throughput with real-time electronic monitoring is possible in the laboratory as both techniques can be run using any real-time PCR machine. Next generation sequencing (NGS) is a fast developing and powerful technology that has the capacity to identify, characterise and confirm one or more known viruses in a sample (Martin et al 2016). It can also be used to identify previously uncharacterised viruses, which might be associated with diseases of unknown cause. It is not uncommon to obtain an entire genome of a virus using NGS, which serves as an excellent confirmation of its presence in a sample. NGS is generally low throughput compared to PCR or ELISA, however it is possible to combine several samples into a single NGS run and use tags to differentiate between sequences from each sample. Due to the cost and complexity of sample preparation and data analysis and the time required to complete these, NGS has most commonly been used as a virus discovery tool in research programs (Kehoe et al 2014). However, as the technology develops the cost of consumable items and equipment is becoming less expensive, the run-time is decreasing and simple analysis pipelines are being developed, which make NGS faster and more accessible as a routine diagnostic tool for detection and/or confirmation of plant viruses. Whilst most NGS platforms are laboratory based, hand held NGS tools are being developed that can be used outside of a laboratory environment, although in the short term they may still require a higher skill level for use and data interpretation compared to other field based methods. When NGS uncovers an unexpected virus, either known or unknown, in a sample it is important to confirm the presence of the virus by another means and ascertain if that virus has biological significance and poses any risk (Martin et al 2016).

What we noted with diagnostics during workshop:

1. National preparedness-target list of exotic and endemic viruses for which tests are most urgently required
2. A co-ordinated approach to virus diagnostics in Australia including:
    - Lab networking to assist the direction of samples to a laboratory with appropriate capacity–who does what/ how
    - Lab accreditation for quality assurance of diagnostics eg NATA, other
    - ELISA reagents-key and less common kits as part of networking
    - List of available PCR tests for virus detection in Australia
    - Development of validated standard protocols-which are adopted nationally for virus detection
    - Identification or development of group specific primers for virus groups to assist with general detection and which viruses they are likely to work for eg scope of primers
    - Access to positive controls-real and synthetic as necessary for ELISA and molecular techniques to improve diagnostic capacity
3. Analysis of diagnostic methods for virus detection: strengths and weaknesses of current methods
4. Analysis of the advantages and limitations of field based/ rapid diagnosis including LAMP, RPA and other technology
5. An in depth analysis of NGS including future use and advantages/ limitations/ role with other molecular and biological data
6. Specific diagnostics-testing of imported vegetable seed-current and future methods/ protocols including likely improvements in sensitivity etc.
7. Virology role in diagnosis of vector borne pathogens eg Liberibacter and phytoplasma

The major recommendation relating to diagnostic was that the key virology diagnostic laboratories develop more targeted collaboration to better service the vegetable industry. The benefits from this recommendation include:

• co-ordination should ensure a more timely response to both endemic and biosecurity incidents and provide a more cost – effective and efficient system

• the recommendation should be facilitated with moderate industry investment with the understanding that timely, accurate diagnosis is critical in implementing management and/ or containment measures

• the recommendation should include other vector borne pathogens, particularly phytoplasma and Liberibacter, given their current importance and the role virologists have traditionally played in their detection and management

• as part of a more co-ordinated approach to viral diagnostics, opportunities should be identified to develop and/or evaluate equipment and protocols which may provide rapid diagnosis outside of major facilities.

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Appendix 3: Workshop-virus diseases of national importance to the vegetable industry May 2016 – Ecosciences Precinct Brisbane

Workshop aims and expected outcomes

Participants in the two day workshop will assist in refining and prioritising virus diseases of importance in levied vegetable crops in major Australian production areas, develop strategies for better management and scope future research, development and extension activities with the aim of reducing industry losses while maximising the return on investment to industry. Both strategic research and transformational project areas will be considered in terms of feasibility, likely investment, expected outcome, likely return on investment and industry impact.

At the conclusion of the workshop participants will have listed viral pathogens of importance to the vegetable industry, determined key areas requiring further R&D to reduce economic impacts, assessed future needs to enhance diagnostics and outlined new potential projects.

Workshop parameters. The project brief was to focus largely on endemic viruses affecting crops under the umbrella of the vegetable levy. This been the case, less emphasis was placed on potato, onion and melons as these crops are covered by their own industry levies. With the exception of processing tomatoes, the tomato industry does not collect a levy but this important Solanaceous vegetable does need to be included in discussions on the epidemiology and detection of viruses in Solanaceous crops.

Workshop program

MONDAY 9 MAY

10 30 am Introduction

10 35 am Setting the scene- workshop objectives and desired outcomes

11 00 am Overview of recent/ current projects in vegetable virology

11 30 am Recommendations from recent final reports

12 noon Participants outline of key issues in their State or area of expertise

12 45 pm Industry perspectives-needs and how best to obtain their input

1 15 pm LUNCH

2 00 pm Where are we with virus management-successes, limitations, failures, what are realistic options

3 00 pm Biosecurity issues-impact, influence on projects on endemic viruses

3 30 pm Break

4 00 pm Current diagnostics-strengths, weaknesses, improvements

5 00 pm CLOSE

TUESDAY 10 May

9 00 am Cross- industry RD&E-synergies, collaborations

9 30 am Future investments-impacts, value for money, scientific value, funding sources

10 30 am BREAK

11 00 am Future plans/potential projects/ recommendations/ group discussion

1 00 pm LUNCH

2 00 pm Discussion period/ Recommendations

4.00 pm Workshop close

Topic 1: Overview of recent and current projects in vegetable virology in Australia

VG 15008 Viruses of national importance to the vegetable industry (Project Leader Denis Persley) Completion date March 2017

VT 13003 Improved productivity of fruiting solanaceous crops through area wide management of insect vectored viruses in Bowen. (PL Cherie Gambley) Completion date May 2017

VT 15013 Improved management options for Cucumber green mottle mosaic virus (PL Lucy Tran) Completion date May 2019

VG 14063 Innovative solutions to management of tospoviruses in vegetable crops (PL Nina Mitter) Completion date January 2019.

VG 10081 Breeding capsicums for tospovirus resistance (Des McGrath) (Final report submitted May 2016).

Resolving critical disease threats to the Western Australian cucurbit industry from new and previous incursions of damaging cucurbit viruses. (PL Roger Jones) Funded by DAFWA and the cucurbit industry.

Recommendations from recent final reports on vegetable virology

VG 10104 Integrated viral disease management in vegetable crops

Final report*:*

- Further work on the management of viruses in vegetable cucurbits should be undertaken, particularly work on tolerant/ resistant varieties and other non-chemical management methods. This work should be in collaboration with growers with a view to demonstrating the value of various methods on-farm, and incorporating them into crop management plans.

- Contribute virology expertise to the development of integrated viral/vector management systems in protected cropping at Virginia SA and elsewhere.

- Continue work on the epidemiology of TSWV in field and greenhouse crops, given its continuing impact on a range of vegetable crops. Use new molecular analysis methods to characterise strains of TSWV in Australia, including resistance-breaking strains.

- Continue to support the adoption of integrated viral disease management as part of industry crop protection programs.

- Investigate opportunities to undertake relevant new work on lettuce big vein disease and other virus diseases with soil borne vectors.

VG0 7128 Integrated viral disease management in vegetable crops

Final report:

- Measures to promote the continued adoption of integrated viral disease management as part of crop protection programs be supported
- Further work be undertaken on the causes, epidemiology, impact and management of lettuce big vein disease
- Further work on area wide management of insect virus vectors be supported including cross industry links to address the broad host ranges of both the vectors and viruses transmitted
- The epidemiology and management of several virus disease outbreaks requires investigation before management systems can be implemented. These include Bean common mosaic virus in beans at Kununurra and Cucumber mosaic virus in capsicum in Carnarvon, WA.
- The expertise and experience of the project team in VG 7128 continued to be supported and used by the vegetable industry to provide professional expertise in virus disease management and biosecurity issues.

VG0 10081 Breeding capsicums for tospovirus resistance

The recommendations from this project included seeking additional funds from the commercial partner and granting bodies to explore the long term durability of tospovirus resistance at a molecular level.

A further recommendation was to screen additional Capsicum germplasm for resistance to resistance breaking strains of TSWV, including the strain which is dominant in the Virginia production area.

It was further recommended that the molecular marker technology developed with the commercial partner be developed to provide marker-assisted selection for Capsicum chlorosis virus in hybrid development.

Topic 2: Key virus disease issues in each State

Tasmania (Calum Wilson)

- No major issues identified and little change from survey data presented for processing crops (peas, beans, carrots, broccoli, cauliflower) as part of VG 7128 final report.
- Polerovirus has been detected at a low level in pea and broccoli while Pea seed borne mosaic occurs at a low level in pea.
- TSWV causes sporadic infection in lettuce and potato once or twice in a decade.

Victoria (Fiona Constable, Brendan Rodoni)

- TSWV in tomato
- Melons-Melon necrotic spot virus at one or more locations. Potyvirus can be damaging to melons and other cucurbits. WMV common and sometimes damaging in zucchini and other cucurbits in Swan Hill- Mildura
- Crinivirus (BPYV) occurs in greenhouse cucumbers
- Phytoplasma diseases can be prevalent in a range of crops, including solanaceous vegetables.

South Australia (Denis Persley and local collaborators)

- TSWV a continuing problem in greenhouse capsicums on North Adelaide Plain (Virginia area). A resistance breaking strain has dominated since TSWV resistant capsicums were introduced in the early 2000s. Management has largely relied on insecticide control of thrips vector(WFT) with overuse and poor understanding of resistance management has led to several major management failures with resultant severe crop losses amounting to millions of dollars. The situation has improved in the last five years with the introduction of biocontrol programs for thrips and other pests and an improvement in farm hygiene and greenhouse construction and management.
- Crop losses, however, still occur and biocontrol has limitations for virus vector management.
- Tomato mosaic virus is an increasing issue in greenhouse capsicum crops on the NAP. Current outbreak identified in about 2009 and is steadily spreading within the district.
- The major variety is susceptible and growers have been reluctant to change to resistant varieties because the standard variety meets the market niche very well. The proximity of farms and family connections make management of this tobamovirus difficult.

- The ophiovirus Ranunculus white mottle virus can be found in many greenhouse capsicum crops, particularly in younger plants. The effects on yield and quality appears minor.
- TSWV is less of an issue in greenhouse tomato crops where the Sw-5 resistance gene seems durable.
- The whitefly transmitted Tomato torrado virus is common in tomato crops and resistance/ tolerance is now a selection criteria for varieties for the Virginia area.
- The crinivirus Beet pseudoyellows frequently reaches very high incidences in greenhouse cucumber crops at or after fruit set. The effects on yield are not known but the high incidence coupled with predisposition to spotted mite and powdery mildew infection because of the severe chlorosis must affect crop longevity and yield.
- Aphid transmitted viruses are seldom an issue in greenhouse cucumber crops.

Queensland (Cherie Gambley)

- Potyviruses, mainly Papaya ringspot virus (PRSV), cause significant crop losses in zucchini, melons and pumpkins annually in all important production areas. Losses are estimated to be approx.. $5M annually. Zucchini yellow mosaic virus occurs sporadically but PRSV is the dominant virus each year.
- Cucumber green mottle mosaic virus (CGMMV) has recently been detected (February 2017) in greenhouse cucumber crops at Bundaberg. The virus was previously detected in an isolated watermelon crop at Charters Towers north Qld and is believed to have been eradicated.
- The tospoviruses TSWV and Capsicum chlorosis virus (CaCV) can cause economic losses in the Bundaberg and north Queensland production areas. CaCV is dominant at Bundaberg while both virus occur in crops in the Gumlu/Burdekin production areas.
- CaCV has occurred more frequently in tomato crops at Bundaberg in the last three years. TSWV has severely affected tomato crops at Bowen in the last four years.
- Tomato yellow leaf curl virus (TYLCV) is common and widespread in all major tomato production areas, with the exception of the Granite Belt.
- Disease incidence and crop losses are frequently high in susceptible varieties in Bundaberg, Bowen and south east Qld. Resistant varieties are essential for profitable crops and are now widely adopted.
- The whitefly transmitted Carlavirus Cowpea mild mottle virus was detected in fresh market French beans in the Fassifern area of south Qld in April 2017 where it caused significant crop losses.
- Sweet potato feathery mottle virus is widespread and common and has high reinfection rates in crops grown from virus tested material
- Further work is required to determine the distribution, incidence and importance of sweet potato leaf curl virus.

Western Australia (Brenda Coutts)

- Cucurbits in Kununurra and Carnarvon are frequently severely affected by zucchini yellow mosaic virus.

- Cucumber green mottle mosaic virus was detected in greenhouse cucumber crops at Geraldton and Perth metro area in 2016.
- TSWV causes sporadic problems in tomato and lettuce in the Perth area and in capsicums at Carnarvon where cucumber mosaic virus is frequently damaging in capsicums. This is the only capsicum production area in Australia where CMV is an issue.

Topic 3: Vegetable industry perspectives-needs and how best to obtain input.

Comment/ data to be obtained from growers, consultants, seed companies and experienced agronomists working in the industry.

A survey form discussed and prepared using input provided. See attached.

Information on the project and a link to the form was in Ausveg weekly update on February 14 2017.

Topic 4: Current virus management-successes, current and future needs.

See attached table

Topic 5: Biosecurity issues-impacts, endemic vs current and future incursions.

Capacity to provide risk analysis and recommendations on virus pathways, risk levels and vectors

A factor underlying biosecurity issues for the vegetable industry is that seed of most crops is imported in large quantities hence risk associated with seed borne viruses can be significant. The international seed industry is complex and gaining intelligence on actual production sites and international movements of parents, seedlots etc is not easy.

Noted that several preventative seed treatments for viruses are no longer used e.g. TSP on tomato seed for TMV control.

Recent incursions have had significant effect on virology resources in several States. Examples include CGMMV in the NT, WA and Qld. ; Tomato potato psyllid/ Liberbacter in WA in 2017 and Cowpea mild mottle virus in Qld in 2016.

Topic 6: Current and future diagnostics-strengths, weaknesses and improvements

Keypoints

- National preparedness- develop a target list
- Group specific primers-define scope of which primers detect which specific viruses
- Develop a list of primers/ antisera available in key labs
- Access to positive controls-consider developing synthetic controls if necessary
- Protocols for testing for key pathogens

- Develop/ improve network of diagnostic labs for viruses/ phytoplasma/ Liberbacter

Other points :

- NGS in diagnostics will become more widely used and cheaper in the next five years
- Caution on using NGS data alone and need for further diagnostics and biological work to determine relevance of data
- Opportunities to develop collaborations in library preparation, cost sharing, data analysis
- Other diagnostic methods e.g. LAMP, lateral flow
- Maintenance /active use of virus reference collections

Virus records :

- -Support revision of Viruses of plants in Australia (Buchen-Osmond et al. 1988) as database in particular
- Among other things, revision will allow validation of old and at times dubious records
- Better, more accurate data to support not known to occur records for area freedom, export crops etc. Improved market access can result.

Topic 7: Cross industry R, D &E-synergies and collaborations

Opportunities for cross industry projects available but formal projects across RDCs are usually not easy to develop and fund. More likely to succeed if there is both in –kind and cash contributions, role and contribution of each partner is well defined and there is a "good news" aspect to the partnership.

Opportunities:

- Diagnostics projects-grains/ cotton/ vegetables-poleroviruses and aphid vectors
- Cucurbits and grains- potyviruses
- Virus/ vector epidemiology-whitefly/ aphids/ phytoplasma-current significant issue in grain legumes and solanaceous vegetables
- Black bean aphid *Aphis fabae*as a possible incursion and efficient vector of viruses infecting potato, other vegetables and grain legumes
    - Cowpea mild mottle virus in fresh green beans, soybeans, mung beans

Topic 8: Recommendations/ future investment

Major Themes

Virus diversity/ dynamics/ reservoir hosts

Resistance mechanisms

Vector diversity/ dynamics

Shelf life/ quality/ nutrition

Diagnostics-endemic and biosecurity pathogens

Broad support base

Area specific/ emerging issues

Students/ training

Future investment

Background

Success based on resistance, area wide management and commodity/ virus approach

Resistance-work should be directed to include the following as applicable:

- Collection of base line data to assist screening process. Maintain isolate collections as part of this.
- Evaluation of germplasm
- Phenotyping/ genotyping of isolates/ strains; virus characterisation
- Resistance breakdown
- Novel resistance strategies, particularly where non transgenic plants are produced e. g. RNAi, gene editing
- Collaboration with seed companies/ Hort Innovation etc investment

Area wide management of virus/ vectors

- Need to include all crops in area so ways of handling non levy crops need to be devised
- Components/ collaborations
- Monitoring vectors/ virus
- Control using chemicals/ biocontrol/ hygiene and other relevant components
- Extension/ participation of local councils, grower groups, local industry and consultants

Commodity/ virus approach

An example is capsicum/ CMV at Carnarvon WA where there is an important local issue not reflected elsewhere in Aust/.

Suggested project areas

Tospoviruses

- Genetic variability with strains including resistance breaking; isolate variation and possible frequent recombinations with 3 components. Strain fitness re vector and fitness of resistance breaking vs wild types and possible recombinants.
- Are there other tospos in crops/ weeds?
- Target crops-capsicum and lettuce
- C/B of work to date; value of biocontrols/ vegetation management, resistant vars or consequences of resistance failure etc
- Management in field and protected cropping
- Isolate collection and characterisation
- Vector biology/ diversity/ differential transmission and efficiency across tospo and thrips species/ molecular ID of thrips species.
- CaCV-host range/ alternative hosts/ vector species/ virus distribution
- Lettuce- importance, management to reduce losses eg hygiene, reflective mulches; UV absorbing covers
- Thrips-prediction of population dynamics, hosts etc

Viruses in cucurbits

- CGMMV, MNSV, Potyviruses
- Importance, distribution, epidemiology of MNSV in Australia
- Potyviruses-distribution, vector presence/ variability
- Resistance and resistance mechanisms. Not well understood-lit review, tolerance, virus inoculum levels, time of infection/ variety effects. Resistance /tolerance screening in collaboration with seed companies. Base data on viruses and variability in Australia
- Alternative resistance strategies using new molecular techniques
- Seed transmission of WMV
- CB analysis of potyvirus tolerant zucchini varieties
- Basically PRSV in Qld, WMV Victoria and ZYMV in WA. ZYMV does occur in Qld.
    - Regional issues:
    - Impact locally
    - Adapted varieties
    - Virus strain/ vector typing
    - Assessment of new material

Biology of virus and vectors in the Australian environment

- A critical area where there has been little activity for some years.
- Research areas could include
- Vector monitoring and population dynamics
- Population structure
- Modelling/data collection during major epidemics. An example would be the major BYV epidemic in canola in SA and Victoria and GPA. Valuable data was probably not collected as we lack the capacity to quickly respond in these cases and gather the valuable base data
- Projects would support higher degree students or post docs
- Projects would target major vector groups-aphids, whitefly, thrips
- Phytoplasma/ leafhoppers and Psyllids/ Liberibacter should also be considered given recent outbreaks

VG 15008 Workshop Participants

Dr Calum Wilson	Tasmanian Institute of Agriculture, Hobart
Dr Fiona Constable	Agriculture Victoria, Bundoora Vic
Dr Brendan Rodoni	Agriculture Victoria, Bundoora Vic
Dr Brenda Coutts	Dept Agriculture and Food, South Perth WA
Dr Cherie Gambley	Department of Agriculture and Fisheries (DAF), Applethorpe, Qld
Dr Paul Campbell	DAF, Ecosciences Precinct, Dutton Park, Qld
Denis Persley (Convenor)	DAF, Ecosciences Precinct, Dutton Park, Qld
Dr Andrew Geering	QAAFI/University of Queensland, Dutton Park, Qld
Dr Ben Callaghan	HORT INNOVATION Brisbane, Qld

Summary of current situation with management of virus diseases in vegetables

CROP	VIRUS	CONTROL	ISSUES	PROGRESS IN CONTROL	OTHER VIRUSES
Lettuce	LMV LUYV	Good seed quality Good hygiene; insecticides	TSWV LBVD	Same but remains an issue Some progress – importance to industry poorly defined. Factors affecting severity incompletely known.	BWYV CMV TuMV
Carrots	CVY ApVY	Good hygiene			
Beans	BCMV	Good resistance	CPMMV (Qld) BCMV Borlotti bean; vars not resistant	Unknown	Summer death
Brassicas	Polerovirus BYV	Good; not an issue			
Capsicum (chilli)	Tospovirus TSWV; CaCV PVY	Not good Good-R vars and	TSWV-RB strains increasing in prevalence. CaCV sporadic no commercial R hybrids. Tobanovirus greenhouse crops.	Average tospo and tobamovirus cause economic losses. Work needed to reduce these.	CMV in Carnarvon

CROP	VIRUS	CONTROL	ISSUES	PROGRESS IN CONTROL	OTHER VIRUSES
		reduced prevalence virus			
Celery	CeMV	Adequate			
Beetroot	CMV				
Spinach	AMV	Virus not a problem			
Silver beet	BWYV				
Sweet potato	SPFMV SPLCV		High reinfection rate in 'clean material' with SPFMV		
Sweet corn	JGMV		Avoidance of peak danger period; resistant varieties		
Peas	No significant issues detected				BLRV PeaSBM BWYV SoyDV potential issues

CROP	VIRUS	CONTROL	ISSUES	PROGRESS IN CONTROL	OTHER VIRUSES
Cucurbits Vegetable cucurbits – squash, pumpkins, zucchini, cucumber	CGMMV	Inadequate outbreaks in greenhouse cucumber crops	CGMMV	Too early to decide if greenhouse management will be adequate	
	Potyvirus: PRSV ZYMV WMV	Inadequate	Potyvirus	Some. Tolerant zucchini varieties. Major losses in Qld, WA in melon squash and pumpkin from potyvirus.	CGMMV would become bigger issue in all cucurbits in field x greenhouse

1. What district and state to you grow crops in (e.g Lockyer Valley, QLD)?
2. What is your production system?
Field
Protected cropping
Both
3. What are the major crop or crops you normally grow? (tick more than one if applicable)
capsicum
lettuce
melons
pumpkins/zucchini
tomato
sweetcorn
peas & beans
onions
potatoes
Other (please specify)
1
4. What other crops do you grow? (tick more than one if applicable)
capsicum
lettuce
melons
pumpkins/zucchini
tomato
sweetcorn
beans & peas
onions
potatoes
Other (please specify)
5. What is the approximate size of the major crop you produce?
less than 2 ha
between 2 and 20 ha
more than 20 ha
6. What types of diseases impact your production? (tick more than one if applicable)
viruses
fungal
bacterial
nematodes
None
2
7. Which of the below viruses or diseases do you consider cause significant impacts to production? (tick more than one if applicable)
Tomato spotted wilt virus
Mosaic disease of pumpkin/zucchini/melon
Lettuce big vein disease
Tomato yellow leaf curl virus
Cucumber mosaic virus
Lettuce mosaic virus
Turnip mosaic virus
Beet western yellows virus
Other (please specify)
8. How confident are you in identifying virus diseases?
Very
Able to identify most that affect my crop
Able to identify some that affect my crop
Not at all
Usually refer to my local crop consultant
Other (please specify)
9. How often do you use an official diagnostic service to identify disease outbreaks?
Always

Often
Occassionally
Never

3

10. What influences your decision to use a diagnostic service? (tick more than one if applicable)

Knowing where to send
How quickly you get an answer
Cost
Value of the information provided with the diagnostic
Crop consultant advises to send a sample in
Other (please specify)

11. Which of the below diagnostic services are you familiar with?

GrowHelp, Department of Agriculture and Fisheries, QLD
Crop Health Services, Department of Economic Development, Jobs, Transport and Resources, Victoria
Plant Health Diagnostic Service, Department of Primary Industries, NSW
Horticulture Diagnostic Services, South Australian Research and Development Institute (SARDI)
AGWEST Plant Laboratories, WA Department of Agriculture and Food
Laboratory Services, Primary Industry, Department of Resources, Northern Terroritory
TASAG - Pathogen & Elisa Testing Service, Tasmania
Other (please specify)

12. How often do virus diseases affect your crops?

Every season at high levels
Every season at moderate levels
Every season at low levels
Occasional severe out breaks
Occasional moderate out breaks
Occasional low outbreaks
Never

4

13. What do you estimate the annual yield impact of virus diseases to be for your crops?

Very high > 50%
High 20 - 50%
Moderate 5 - 20%
Low 0 - 5%
Unknown

14. What do you estimate the annual yield impact of virus diseases to be for your crops during a major disease outbreak?

Very high > 50%
High 20 - 50%
Moderate 5 - 20%
Low 0 - 5%
Unknown

15. What do you estimate the annual economic impact of virus diseases to be for your crops? (including direct yield losses & costs to manage the disease)

Very high (> 20%)
High (10 - 20%)
Moderate (5 - 10%)
Low (0 - 5%)
Unknown

16. What do you estimate the economic impact of virus diseases to be for your crops during a major disease outbreak? (including direct yield losses & costs to manage the disease)

Very high (>20%)
High (10 - 20%)
Moderate (5 - 10%)
Low (0 - 5%)
Unknown

5

Crop
Virus disease
Approximate % of crop
affected
Approximate % cost of
production

17. Can you provide an example of a virus disease outbreak in your crop?
18. How do you rate availability of management options for control of major virus diseases of concern to you?
Adequate management options available and used regularly
Poor management options available
No management options available
Management options available but not cost-effective
Uncertain what options are available
Other (please specify)
19. Would you support further work on improved management of virus diseases?
Yes, further work would be highly beneficial
Yes, further work would be beneficial
Yes, further work would be of some benefit
No, current management options are ok
20. Which of the below viruses or diseases do you consider require further work to improve their management? (tick more than one if applicable)
Tomato spotted wilt virus
Mosaic disease of pumpkin/zucchini/melon
Lettuce big vein disease
Tomato yellow leaf curl virus
Cucumber mosaic virus
Lettuce mosaic virus
Turnip mosaic virus
Beet western yellows virus
Other (please specify)
6
7

Appendix 5: Key recommendations for future investment in RD&E

- **The key areas for future investment for more effective virus disease management in vegetable crops are gaining a better understanding of:**
    - **genetic variability of viruses**
    - **disease resistance mechanisms**
    - **vector diversity and dynamics**
    - **product quality**
- **The virus groups with highest priority for future investment are the tospoviruses (Tomato spotted wilt virus) and the potyviruses, particularly those infecting cucurbits**
- **Future investment in the biology and management of the major virus vectors, aphids, thrips and whitefly**
- **Research and development should use the principles of area wide management of viruses and vectors in both field and protected cropping situations**
- **Extension methodology for enhancing the adoption of area wide management be investigated in a specific project**
- **The key virology diagnostic laboratories develop more targeted collaboration to better service the vegetable industry**
- **Investment in the revision of the VIDE database be supported to provide current, accurate data on the presence, distribution and importance of plant viruses in Australia.**
- **The provision of targeted, timely information on viruses and their management to the vegetable industry continue to be a high priority**
- **Linkages across industries and RDCs be encouraged where the biology of the virus and vector would make collaborative work and delivery of outcomes more cost effective, efficient and meaningful**
- **The role of seed as a pathway for virus incursions be investigated**