Australian Government

Australian Centre for International Agricultural Research

Final report

project	**Identifying appropriate strategies for reducing virus and weevil losses in sweetpotato production systems in Papua New Guinea and Australia**
project number	HORT/2011/053 previously PC/2011/053
date published	13 July 2020
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approved by	Australian Centre for International Agricultural Research
final report number	FR2020-009
ISBN	978-1-922345-45-5
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

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1 Acknowledgments

The project team would like to acknowledge our respective organisations—National Agricultural Research Institute (NARI), Australian Sweetpotato Growers Inc. (ASPG), Secretariat of the Pacific Community (SPC) and the Department of Agriculture and Fisheries (DAF)—for their support of this work. We are grateful to ACIAR for providing project funding and their continued interest in the project. In particular, we would like to extend our thanks to Fresh Produce Development Agency, management and staff who, despite having many other commitments, willingly provided so much time and effort to ensure the project was able to meet with Village Extension Workers (VEWs) and the farmers producing commercial sweetpotato crops. We would also like to express our appreciation to National Agriculture Quarantine and Inspection Authority (NAQIA) for assisting in the surveying for sweetpotato weevils.

We are indebted to Dr Rolf Oberprieler (CSIRO) and Dr Chris Reid (Australian Museum) for their assistance in identification of both West Indian sweetpotato weevil and coffee ring borer as pests in PNG sweetpotatoes, and sweetpotato virologist Dr Segundo Fuentes (International Potato Center – CIP) for all his openness and willingness to share his vast knowledge of sweetpotato virology.

We would also like to thank Dorcas Homare, Anna Kawi and Dr Amanda Mararuai for their dedication and assistance during the periods they were involved in the project. A special acknowledgement must also go to Melissa Frazer (DAF, Mareeba) for the interest she has shown and time devoted to editing and formatting the report.

Most importantly, we would sincerely like to thank the Papua New Guinean and Australian farmers who have so willingly provided their time, expertise and knowledge to assist the project attain its goals.

Australian Government

Australian Centre for International Agricultural Research

NARI

Australian Sweetpotato Growers inc

SPC Secretariat of the Pacific Community

Queensland Government

2 Executive summary

Sweetpotato is a significant, year round, staple food in Papua New Guinea (PNG). Estimates in 2000 indicated 81% of the rural population grew sweetpotato (Omot 2012). It is increasingly grown as a domestic market crop, catering to escalating demand from expanding urban centres. National food security and farm sustainability dictate that the crop's major pests and diseases are minimised.

The Australian sweetpotato industry, while much smaller in volume than PNG's, is one of constant growth, increasing by 20% per annum since the 1980s. Markets require roots to be of high quality, with minimal deformity or defects. In both PNG and Australia, viruses have been identified as the major disease issue, while sweetpotato weevils have been seen as the most important insect pest.

Within the broader development goal of increasing the resilience of food security systems, the specific aim of the project is to identify the most promising integrated strategies for managing sweetpotato pests and diseases in PNG and Australia.

Objective 1. To assess the value of pathogen-tested (PT) planting materials in reducing the impact of virus diseases.

Objective 2. To identify the most promising management tactics for weevils in specific production systems.

A review of previous PT (virus-free) studies was carried out and virus reinfection trials conducted at PNG's Highlands Regional Centre, Aiyura. Workshops were held to standardise virus diagnostic protocols, aid skills development of new staff members and update the teams on the latest diagnostic processes. In Australia, a real-time PCR (qPCR) was purchased and installed at DAF's Gatton Research Facility (GRF).

A comprehensive literature review of sweetpotato weevils *Cylas formicarius* (SPW) and West Indian sweetpotato weevil (*Euscepes batatae*) (WISW) was undertaken. Sweetpotato weevil monitoring protocols (Appendix 2) and a farmer sweetpotato weevil awareness survey were developed, reviewed and implemented.

In PNG the project found *Sweetpotato Feathery Mottle virus* (SPFMV) and *Sweetpotato Virus G* (SPVG) to be the most common viruses, with SPFMV predominating. SPFMV+SPVG co-infections were also found. Reinfection and yield decline trials indicated that the commercial PNG sweetpotato varieties may have tolerance to these potyviruses. There are indications, needing confirmation, of other viruses affecting sweetpotato in PNG.

In Australia the development of qPCR led to the confirmation of *Sweetpotato leaf curl virus* (SPLCV) in the major sweetpotato production regions. This was identified as a new virus for Australia.

Sweetpotato weevil studies found WISW in 16 PNG provinces, covering highlands, lowlands and islands regions. WISW was found to be active at higher altitudes (2 300 m above sea level) than SPW (1800 m above sea level). At altitudes suitable to both species, WISW and SPW were found to cohabit in plant storage roots, crowns and stems. A key was developed to identify larvae of SPW and WISW. A third weevil, thought to be coffee ring borer (*Meroleptus cf. cinctus*), was found infesting sweetpotatoes in the Eastern Highlands Province.

Surveys showed that, although farmers are well aware of the damage caused by sweetpotato weevils, they have no understanding of weevil lifecycles or, in fact, that the larvae found in roots, crowns and stems are related to the adult weevil. Weevil resistant sweetpotato varieties were also unknown to farmers. While most farmers receive no agricultural information, those that do obtain it from either the National Agricultural Research Institute (NARI) or Fresh Produce Development Agency (FPDA).

As, on the whole, trial work has shown an advantage in using PT planting material and co-operator farmers involved in this and previous projects are convinced of its yield and quality benefits, a PT scheme should be initiated. Virus reinfection studies should also be continued at farm level. It is believed that there are more viruses affecting sweetpotato than have been reported, so there is a need to continue surveys in both PNG and Australia and further develop diagnostic technologies. Virus diagnostic workshops have greatly improved the communication and collaboration between regional sweetpotato scientists and International Potato Center (CIP), and should be continued.

Given the ample food sources available to sweetpotato weevils their eradication will not be possible; managing the farming system to minimise the effects of the weevils must be the focus. It is believed an area wide management (AWM) strategy would be most suitable. This will require farmer education of weevil biology and ecology, and a participatory research process to empower farmers to implement the strategies they develop.

3 Background

Sweetpotato is the staple food of Papua New Guinea (PNG). It is grown for household use and, since the 1980s, increasingly for cash on domestic markets. Depending on the region, it may occupy 55–90% of the arable land, producing an estimated 2.87 million tonnes per year valued at A$700 million, calculated as the cost of rice imports to provide equivalent food energy (Bourke and Vlassak 2004).

In recent years, with growing concerns of food and nutritional insecurity in PNG, the crop has figured largely in ACIAR's portfolio of projects addressing factors limiting production, such as soil fertility, pests and diseases, and marketing.

Project SMCN(CP)/2004/071 *Reducing pest and disease impact on yield in selected PNG sweetpotato production systems* concentrated on yield decline and clearly demonstrated that viruses are implicated by comparing pathogen-tested (PT) material with non-PT material of the same varieties. This was followed by a bridging SRA, PC/2010/026 *Validating and documenting a strategy for producing virus-free sweetpotato planting material in Papua New Guinea*. A sister project HORT 2005/134 *The use of pathogen-tested planting materials to improve sustainable sweetpotato production in Solomon Islands and Papua New* Guinea developed farmer field schools, identified the predominate varieties used in Solomon Islands and exported them to be pathogen tested. At a planning meeting in Brisbane in March 2011 ACIAR; researchers from Queensland's Department of Employment, Economic Development and Innovation (DEEDI, later DAFF then DAF); PNG's National Agricultural Research Institute (NARI); and the Secretariat of the Pacific Community (SPC) agreed it was necessary to complete the work on PT and to begin research on sweetpotato weevils.

The PNG Country Consultation in August 2011 endorsed this strategy and agreed to a two year project, PC/2011/053 *Assessing sweetpotato production systems to overcome the effects of virus and weevils in Papua New Guinea and Australia*, pending the completion of two other ACIAR projects: (i) SMCN/2004/067 *Soil fertility management in the PNG highlands for sweetpotato based cropping systems* and (ii) SMCN/2012/016 *Review of research needs on natural resource management and crop protection for sweetpotato-based cropping systems in Papua New Guinea*. Completion of these projects and PC/2011/053 would bring the knowledge of pest and disease management to an adequate level to create a basis for a fully integrated approach to crop management.

The overall aim of PC/2011/053 was to increase the resilience of food security systems in PNG and Australia, with the specific objectives of completing the assessment of PT (virus-free) planting material and the feasibility of changing production practices for the management of weevils.

Project partners were NARI, DAF, Australian Sweetpotato Growers Inc. (ASPG), SPC and the International Potato Center (CIP), Peru. The intention was for NARI to take charge of trials in the PNG highlands to determine yield decline over successive plantings. Samples would be taken for virus analysis and sent to newly equipped centres in NARI, SPC's Centre for Pacific Crops and Trees (CePaCT) (to build regional capacity), and to DAF's Gatton Research Facility (GRF), Australia, with CIP backstopping the work with supplies of unique primers for PCR. GRF would continue to assay plants for hitherto undetected viruses in Australia and, with SPC, refine virus diagnostic techniques for use with real-time PCR (qPCR) and PCR. The outcome of the work was to provide the information required to design a 'clean seed system' (nuclear stock program), if that was the intention of the PNG government.

In parallel with the research on viruses, PC/2011/053 was designed to start work on sweetpotato weevils with NARI and test approaches developed in Australia. A first priority was a literature review on weevil trapping, followed by a planning meeting to organise a survey to provide baseline information on sweetpotato weevils, in weed reservoirs and sweetpotato gardens throughout the country, and to record growers' experiences. The weevils of interest were *Cylas formicarius* (SPW) and *Euscepes batatae* (previously *Euscepes postfasciatus*) the West Indian sweetpotato weevil (WISW). Knowledge from the surveys would then be used to develop best practices for sweetpotato management.

4 Objectives

Within the broader development goal of increasing the resilience of food and nutritional security, the specific aim of the project is to identify the most promising strategies for managing sweetpotato pests and diseases in PNG and Australia.

Objective 1. To assess the value of pathogen-tested (PT) planting materials in reducing the impact of virus diseases.

Objective 2. To identify the most promising management tactics for weevils in specific production systems.

5 Methodology

The project began in September 2012, but a planning meeting to review activities and assign responsibilities was delayed until completion of the sweetpotato manual *Growing healthy sweetpotato: best practices for producing planting material*, written under SRA PC/2010/026.

A course on the use of sweetpotato virus indicator plants was held for new members of the project team unfamiliar with the production of pathogen-tested (PT) sweetpotatoes at Highlands Regional Centre (HRC), Aiyura, Papua New Guinea (PNG) in November 2012. This was followed by a visit to Australia in December 2012 for in-depth training in sweetpotato virology using indicator plants and NCM-ELISA. Sweetpotato agronomy and field trial design and analysis were also addressed. The new team members also became familiar with the sweetpotato weevil, *Cylas formicarius* (SPW), to give them the background needed for their work under PC/2011/053.

In the same month a workshop was held with senior members of the project team from Australia and PNG, at the Department of Agriculture and Fisheries (DAF) Bundaberg Research Facility, to discuss the format for the sweetpotato virus reinfection trials and plan surveys.

An extension of the project was agreed in June 2013 to enable a third series of the sweetpotato virus reinfection trials to be conducted. This extension also provided funds to PNG's National Agricultural Research Institute (NARI) for replacement of an autoclave at HRC, Aiyura.

Further meetings of the project team occurred: (i) August 2013 (Suva, Fiji) for a technical review of activities in the first year, (ii) November 2013 (Brisbane, Australia) to discuss the results of the Fiji virus workshop and meeting and to prepare for the up-coming mid-term review and (iii) December 2013 (Goroka, PNG) for the mid-term review and planning for the second year.

In July 2014 a teleconference was used to discuss project progress and the project final review was held at Bubia, PNG in May 2015.

Project activities for Objective 1 concerned an assessment of the value of PT planting materials in reducing the impact of virus diseases; these went ahead as planned.

First, a technical review of PT trials—mostly those carried out at HRC Aiyura—was completed, and circulated after reanalysis of the data. Second, sweetpotato virus reinfection studies began at HRC Aiyura to assess the benefit of PT compared to field grown varieties; this was less successful because of frequent staff changes and the large amount of work involved. In order to solve these difficulties the project used the Fiji virus workshop to redesign the trial and sampling procedures. The number of varieties was reduced from four to three and fewer samples taken for virus analysis. In addition, virus indexing capabilities were to be reinforced with assistance provided by Secretariat of the Pacific Community (SPC) Centre for Pacific Crops and Trees (CePaCT) using PCR.

Real-time PCR was introduced to the Australian industry at DAF's Gatton Research Facility (GRF). The focus of this technology was to develop procedures to ascertain if begomoviruses (not able to be detected by NCM-ELISA) are infecting sweetpotatoes.

Changes in PNG staff meant that new recruits had to be trained in virus-indexing, and to that end a virus diagnostics workshop was held at GRF in November 2014, conducted by an expert from the International Potato Center (CIP), Peru. This was assisted by The Crawford Fund sponsoring researchers from PNG. The workshop involved both theory and practical training in the use of four virus diagnostic tools: indexing on indicator plants, NCM-ELISA, qPCR and loop-mediated isothermal amplification (LAMP). Considerable emphasis was given on the interpretation of results from the different methods.

In addition to completing the work of SRA PC/2010/026, the project concluded activities of HORT2005/134 *The use of pathogen-tested planting materials to improve sustainable sweetpotato production in Solomon Islands and Papua New Guinea*. Varieties collected by the project from Solomon Islands and sent to Australia for pathogen-indexing were transferred to SPC to complete the task.

Sweetpotato weevil management, Objective 2, began soon after the visit to Queensland by NARI entomologists in late November 2012. A questionnaire to determine farmers' perceptions and attitudes to sweetpotato weevils was devised and tested in the Aiyura area in January 2013. An extensive survey of villages in three highlands provinces—Eastern Highlands (EHP), Western Highlands (HP) and Jiwaka (JP)—between 1 500 and 2 300 m above sea level (from Yonki to Tambul) was then undertaken in April, July and December 2013. Further surveys were carried out in 2014 in Central Province (CP), an area with increasing sweetpotato production due to its close proximity to Port Moresby. To assist the surveys and update a review done by the first project, a literature review of life histories, ecology, management and control of the weevils SPW and West Indian sweetpotato weevil (WISW) was carried out in the first year. To complement the review, fact sheets were written on weevils and wireworms and these were also used during surveys and training.

The results from the highland surveys were unexpected. It had been thought that WISW was confined to the Aiyura region of EHP. However, surveys showed it was widespread in the highlands, requiring further surveys throughout PNG. To date surveys have been completed at 150 sites in 14 provinces. These surveys have been carried out by new trained entomologists (two senior staff left the project in December 2013) and by Village Extension Workers (VEWs) trained in sweetpotato biology and area wide management (AWM) at workshops in 2014 and 2015.

6 Achievements against activities and outputs/milestones

Objective 1: To assess the value of pathogen-tested (PT) planting materials in reducing the impact of virus diseases

No.	Activity	Outputs/ Milestones	Completion Date	Comments
1.1	Technical review on PT	Report	Year 1, month 2	Report completed.
1.2	Trials in PNG—successive planting of PT varieties	Yield decline determined	Year 3, month 1	Two trials completed. Third trial was considerably delayed due to access issues to the tissue culture laboratory at Aiyura. Issues have been resolved and the third trial is in ground.
1.3	Virus reinfection assays	Virus reinfection determined	Year 3, month 4	Virus reinfection testing for first two trials complete. Reinfection data for the third trial will be completed after trial has been harvested.
1.4	Establish virus indexing facilities (at SPC CePaCT and NARI)	Virus indexing facilities New autoclave shipped and setup in a timely manner	Year 1, month 3	PNG staff trained and efficiently conducting herbaceous indexing and NCM-ELISA. Training course held at SPC and Australia for PNG and SPC staff. Solomon Island germplasm held in Australia transferred to SPC CePaCT, Fiji for pathogen testing. Equipment issues with conducting PCR in SPC have delayed testing. PNG samples sent to SPC for diagnosis. Not completed. Second set is being prepared for sending to Australia, along with repeat samples. Funds sent, autoclave ordered and expected on site at HRC Aiyura by October 2015.
1.5	Diagnostics developed for begomoviruses in Australia, PNG & SPC	Strains of begomoviruses identified	Year 2, month 12	Diagnostics using qPCR developed for sweetpotato begomoviruses in Australia and by conventional PCR in SPC. Indicator plant indexing and NCM-ELISA skills improved in PNG. Sequencing of begomovirus currently underway by DAF. Virus diagnostics workshop held at GRF in November 2014. Attended by CIP, NARI, SPC and DAF. Crawford Fund sponsored two NARI scientists.

1.1 The *Review of sweetpotato PT in Papua New Guinea* (PNG) covers:

- a PT methodology trial
- four PT and non-PT comparison trials using Australian and PNG varieties that had been pathogen tested in Australia or Secretariat of the Pacific Community's (SPC's) Centre for Pacific Crops and Trees (CePaCT) and re-imported to PNG
- a PT and non-PT comparison trial using PNG produced PT varieties
- five on-farm PT and non-PT comparison trials.

Overall, the review highlights the benefit of using PT materials both on research stations and in farmer's fields.

1.2 PT material used in the first reinfection trial produced significantly more marketable roots and total root weights than non-PT. The PT planting material average yield was 33.7 t/ha compared with 25.5 t/ha for non-PT material.

The second reinfection trial was more complicated. Growing conditions were poor, reducing yields. Varietal interactions were greater than the generational material effects. PT Beauregard, the control variety, produced significantly higher marketable and total yields than Generation 2 or non-PT, but this difference did not occur with Whagi Besta Minj 2 or Sinato Goroka.

Due to unforeseen issues involving the tissue culture facilities at Highlands Regional Centre (HRC), Aiyura, PNG the planting of the third trial was delayed considerably. The trial could not be planted until February 2015, so the results are not yet available.

1.3 First reinfection trial harvested and assessed for virus reinfection using *Ipomoea setosa* and NCM-ELISA. Results showed:

- non-PT material with significantly more virus infection than PT, *Sweetpotato Feathery Mottle virus* (SPFMV) or *Sweetpotato virus G* (SPVG)
- non-PT showed significantly more multiple virus presence (SPFMV and SPVG)
- the variety Sinato Goroka had significantly lower incidence of SPFMV
- the NCM-ELISA test gave faint indication of two other viruses. The result needs to be checked.

Virus assessments of the second trial showed a higher level of virus throughout.

- SPFMV was present in all treatments, although not in all the plots of PT material.
- SPVG was predominately in Generation 2 and non-PT treatments.
- Overall, there were no significant differences between variety and planting material and the presence of virus.
- There were significant variety and planting material interactions for virus presence.
- The NCM-ELISA test gave some feint indication of two other viruses. The result needs to be checked.

Samples have been sent to SPC for PCR testing. To date this has not been done due to the failure of the agarose gel camera, which was only resolved in June 2015.

The third trial has not yet reached sampling stage.

1.4 Solomon Island varieties held in Australia were transferred to SPC CePaCT where they will undergo pathogen testing and be made available to Solomon Islands and elsewhere. These varieties are:

- Tombe
- Atara
- Nambo
- KSP 02 3 month
- Kaulogo
- Zozoko
- Gova TG27
- Sonoma
- Mouna
- Kotina
- Bugotu
- Tauvusi TFS 021
- Isa TG O2

A training workshop with all project partners (PNG, Australian and Fiji) was conducted at SPC CePaCT on 26–30 August 2013. This was the first time that all PT project officers had been able to meet. Information exchange, exploration of techniques and standardisation of virus testing procedures were achieved.

In October 2014, 44 samples were sent from PNG to SPC for PCR testing. It is expected that now the PCR equipment has been repaired the tests will be done.

SPC has also experienced problems in growing *I. setosa* to a size suitable for grafting, limiting the ability to conduct indexing and NCM-ELISA tests.

1.5 During 2013 and 2014 a laboratory at the Department of Agriculture and Fisheries (DAF) Gatton Research Facility (GRF) was renovated. Reagents, primers and other equipment for real-time PCR (qPCR) were obtained. The qPCR machine was operational by September 2014 and is being used to test for *Ipomoea vein mosaic virus* (IVMV), *Sweetpotato Chlorotic Stunt virus* (SPCSV), SPFMV, SPVG and *Sweetpotato leaf curl virus* (SPLCV).

As a result of this technology, the presence of SPLCV in Australia sweetpotato production regions has been confirmed.

During November 2014 a sweetpotato virus diagnostics workshop was conducted at GRF and at Rockhampton in Queensland. Dr Segundo Fuentes, virologist at the International Potato Center (CIP) discussed the latest protocols and held practicals on NCM-ELISA, qPCR and loop-mediated isothermal amplification (LAMP). He also updated participants on new sweetpotato virus diagnostic technologies under development (e.g. Microarray). National Agricultural Research Institute (NARI), SPC and DAF scientists participated in the workshop. The Crawford Fund sponsored two NARI scientists to attend.

Objective 2: To identify the most promising management tactics for weevils in specific production systems

No.	Activity	Outputs/ Milestones	Completion Date	Comments
2.1	Technical review — weevil trapping in tropical/subtropical cropping systems	A report	Year 1, month 11	Review completed.
2.2	Project planning meeting	Work plan for year 1	Year 1, month 2	Planning meeting completed.
2.3	Initial weevil monitoring survey	Report on a) weevil population, b) hosts, and c) other species over an 18 month period	Year 2, month 9	150 surveys completed covering 14 provinces.
2.4	Develop community/farmer awareness in PNG and Australia	Communities familiar with biology and ecology of two weevil species over 18 month period	Year 2, month 9	50 surveys of farmer knowledge conducted during farm visits. Training provided with each survey conducted. Kaukau fact sheets 6, 7 and 8 produced. Train 56 EHP farmers and 51 Jiwaka/WHP farmers in AWM in March 2015. Presentations at ASPG grower field days at Cudgen, Gatton and Bundaberg.
2.5	NARI project meeting	Work plan for year 2	Year 1, month 11	Project review and planning meeting held at Goroka December 2013.
2.6	Project results used to develop ACIAR sweetpotato project	Results provided to ACIAR planning meeting	Year 2, month 1	Project results provided for development of new ACIAR-funded projects.
2.7	Field trials—weevil management tactics determined on outcome of 2.5 meeting	Data for weevil IPM		With widespread finding of *Cylas formicarius*, *Euscepes batatae* and a third weevil believed to be *Meroleptus cf. cinctus* (coffee ring borer) the focus was changed from field trials to extension of AWM techniques for control of sweetpotato weevils.

2.1 The 33 page review *Sweetpotato weevils of Papua New Guinea and Australia* includes information on both sweetpotato weevils *Cylas formicarius* (SPW) and West Indian sweetpotato weevil (*Euscepes batatae*) (WISW), covering:

- identification/taxonomy
- ecology
- lifecycle
- adult fertility
- adult mobility/flight
- death feigning
- alternate hosts
- distribution and habitat in Australia and PNG

- sweetpotato monitoring and control.

The review has been distributed on the KauKauNet (email list) network, and has been made available to officers of Northern Australia Quarantine Strategy (NAQS) who have included WISW as a pest to watch for.

2.2 A project planning meeting was held at Bundaberg Research Facility in November 2012, in conjunction with the PT and weevil sweetpotato training course for PNG staff.

2.3 Comprehensive sweetpotato weevil surveys were conducted in January, April, July and December 2013. In these surveys SPW were trapped by use of pheromone lures on sticky traps left in the field for 24 hours. WISW was detected by incubating root and vine samples at HRC Aiyura (Table 1). Further comprehensive surveys were undertaken in Eastern Highlands Province in July 2014 and in January 2015 in Central Province. Additional collections were made by NARI staff when on tour. In total, 150 surveys have been conducted. The provinces where surveys have been conducted are Autonomous Region of Bougainville (AROB), Central Province, East New Britain Province, Eastern Highlands Province (EHP), Gulf Province (GP), Jiwaka Province, Madang Province, Manus Province, Milne Bay Province, Morobe Province, National Capital District, New Ireland Province, Sandaun Province, Simbu Province, Western Province (WP) and Western Highlands Province (WHP).

GP and WP are the only provinces surveyed where WISW has not been found. In the AROB, WISW was found on Nissan Island but has not yet been found on Buka or Bougainville islands.

A survey of WISW in the Aiyura valley, an area known to have a heavy presence of WISW, found 27 roots out of 100 collected had WISW infestations.

In December 2014 it was realised that a number of insects that had been collected and previously thought to be WISW were in fact another insect. Initial thoughts are that it might be *Meroleptus cf. cinctus* (coffee ring borer) (CRB) and samples have been sent for positive identification. The three weevils (SPW, WISW and CRB) were found at 12 sites in EHP. At this stage the occurrence of CRB infesting sweetpotato in other provinces is unknown.

Table 1. Summary of Papua New Guinea sweetpotato weevils (*Cylas formicarius* and *Euscepes batatae*) surveys 2013 and 2014

Site	Province	Elevation (m)	*Euscepes batatae* presence	*Cylas formicarius* (average of 24 hour counts on pheromone lure sticky trap)
Bougainville Island (NAQIA survey)	Autonomous Region of Bougainville (AROB)		N	
Nissan Island	AROB	14	Y	
Notave	AROB	276		136
Laloki 2	Central	32		69
Laloki 1	Central	34	Y	379
Works Round Wara-Sogeri-Kairiku Hiri	Central		Y	
Yamuna-Beirena	Central		Y	
Saruakeina-Rigo	Central		Y	
Wama-Kairiku Hiri	Central		Y	

Site	Province	Elevation (m)	*Euscepes batatae* presence	*Cylas formicarius* (average of 24 hour counts on pheromone lure sticky trap)
Bore-Rigo	Central		Y	
Gamogolo-Rigo	Central		Y	
Adoa-Kairiku Hiri	Central		Y	
Sivigolo-Rigo	Central		Y	
Iaiow ari (Sogeri)-Kairiku Hiri	Central		Y	
Karakodubu-Kairiku Hiri	Central		Y	
Alkinamu-Kairiku Hiri	Central		Y	
Moregaina-Rigo	Central		Y	
Kasam pass	Eastern Highlands	1312		
Kami roadside	Eastern Highlands	1428		168
Negomoka	Eastern Highlands	1440		85
Mando (Mamba) Daulo	Eastern Highlands	1461	Y	3
Ifiufa-3 kona	Eastern Highlands	1463	Y	42
Kefamo	Eastern Highlands	1471	Y	45
Gireks	Eastern Highlands	1473	Y	45
Henganoffi	Eastern Highlands	1481		96
Metiyufa	Eastern Highlands	1487	Y	93
Massey	Eastern Highlands	1539	Y	8
Kopafo 1-Bena bena	Eastern Highlands	1559	Y	243
Kopafo 2-Bena bena	Eastern Highlands	1559	Y	199
Gorapi Bridge	Eastern Highlands	1581		28
Ehi	Eastern Highlands	1597		1
Matehau-Fruitgate	Eastern Highlands	1597	Y	85
Onomuna	Eastern Highlands	1603	Y	243
Onomuna	Eastern Highlands	1603	Y	168
Kenemba	Eastern Highlands	1616		135
Kefamo	Eastern Highlands	1621	Y	93
Ifiufa (kaukau market)	Eastern Highlands	1634	Y	129
Notofana	Eastern Highlands	1640		13
Yonki/Kainantu/5 mile	Eastern Highlands	1644	Y	37
Aiyura, Green compound	Eastern Highlands	1660	Y	0
Negemoka, Kabiufa 2	Eastern Highlands	1666		141
Haparira	Eastern Highlands	1675	Y	9
Aiyomontena, Kainantu	Eastern Highlands	1675	Y	0
Mando (Mamba), Daulo	Eastern Highlands	1682		28
PNK Ifiufa	Eastern Highlands	1684	Y	51
Beneveto	Eastern Highlands	1690		174
Kongi/Keremu	Eastern Highlands	1697		4
Mereiaka	Eastern Highlands	1703		30
Kontiyufa	Eastern Highlands	1738		25
Tarabo (Okapa)	Eastern Highlands	1770		37
Kotuni	Eastern Highlands	1985		0
Kotuni (Gahaku LLG)	Eastern Highlands	1985		0

Site	Province	Elevation (m)	*Euscepes batatae* presence	*Cylas formicarius* (average of 24 hour counts on pheromone lure sticky trap)
Basenengka	Eastern Highlands	1598	Y	
Gireku (Kasena)	Eastern Highlands	1696	Y	34
Kerevat Market	East New Britain	26	Y	
East New Britain Province (NAQIA survey, 22 sites)	East New Britain		N	
Gulf Province (NAQIA survey, 9 sites)	Gulf		N	
Gusamp	Jiwaka	1569	Y	245
Highway 2	Jiwaka	1571		
Tombil	Jiwaka	1576	Y	41
Tapimemb, Minj Junction	Jiwaka	1578	Y	
Minj guest house	Jiwaka	1591	Y	153
Waraka/Fatima	Jiwaka	1592	Y	
Opposite Alta Orange	Jiwaka	1598	Y	
Konabel, North Waghi	Jiwaka	1602		556
Minj Junction	Jiwaka	1607		76
Pukamil	Jiwaka	1613	Y	577
Kondela next Jiwaka Timbers	Jiwaka	1629	Y	
Domil	Jiwaka	1633	Y	111
Dobel	Jiwaka	1633		123
Waraka	Jiwaka	1641		332
Matupi Plantation	Madang	5		165
Mono-Malala	Madang	10	Y	163
Balama	Madang	32	Y	494
Erima	Madang	32	Y	275
Ambung (Tungu)	Madang	383		525
Sevan	Madang	300		707
Pelipatu	Manus	137	Y	
Tulu 1	Manus	141	Y	
Kari	Manus	453	Y	
Alotau Market	Milne Bay	7	Y	
NARI Bubia	Morobe	24		247
Kapasung	Morobe	51		138
Tumua	Morobe	422		56
Ramu Market	Morobe	427	Y	
Bulolo Market	Morobe	647	Y	
Wau Market	Morobe	1092	Y	
Port Moresby-market	National Capital District		Y	
Kavieng	New Ireland		N	
Tambran, Kerowagi	Simbu	1473	Y	
Meraneh	Simbu	1575	Y	413
Vanimo (x 6 sites)	Sandaun		N	
Kundiawa	Simbu	1575	Y	

Site	Province	Elevation (m)	*Euscepes batatae* presence	*Cylas formicarius* (average of 24 hour counts on pheromone lure sticky trap)
Gon Kambua Primary School	Simbu	1623	Y	28
Gera, Sina Sina	Simbu	1844	Y	0
Western Province (NAQIA, 5 sites)			N	
Dobel	Western Highlands	1646	Y	
Kuntila (Kunta?), Kelua, Hagen Central	Western Highlands	1649	Y	94
Dobel	Western Highlands	1664		123
Panga, Keleu, Hagen Central	Western Highlands	1805	Y	51
Kiripia Mission	Western Highlands	2103		0
Mogha/Moka	Western Highlands	2110	Y	0
Kiripia	Western Highlands	2145		0
Alkena	Western Highlands	2201		0
Puluwa	Western Highlands	2205	Y	0
Tambul	Western Highlands	2239	Y	0
Tambul Baibel Skul	Western Highlands	2255		0
Tambul HRC	Western Highlands	2255	Y	0
Alkena turnoff	Western Highlands	2264		0
Abungo Bridge	Western Highlands	2285		0
Opiopul	Western Highlands	2285	Y	0
Junct Tambul/Kiripia/Giluwe	Western Highlands	2296	Y	0
Junct Tambul/Enga	Western Highlands	2308	Y	0
HRC Tambul south east	Western Highlands	2309	Y	
Yawer Village	Western Highlands	2311	Y	0
Tambul Catholic church	Western Highlands	2311	Y	
HRC Tambul north east	Western Highlands	2313	Y	
Guesthous Tambul Baibel Skul	Western Highlands	2314	Y	0
HRC Tambul near office compound	Western Highlands	2317	0	0
HRC Tambul old sweetpotato trial site	Western Highlands	2317	0	0
HRC Tambul EU ACP trial site	Western Highlands	2317	0	0

Blank space = no data.

0 = no *Cylas formicarius* were found at the survey site after 24 hours using pheromone with sticky traps.

N = no *Euscepes batatae* were found at or reared from samples taken.

Y = *Euscepes batatae* was found at or reared from samples taken.

Table is aligned by province and elevation.

2.4 The 50 farmers interviewed clearly recognise the severity of damage caused by the weevil larvae in the storage roots or crowns, but have little understanding of their ecology or biology. The adults are recognised but not associated with their destructive larva. Generally, farmers have no control practices for weevil control.

During each sweetpotato weevil survey extension in weevil biology and management was provided to the farmer and others present. During the July 2013 survey more than 200 people were contacted, and from May 2014 to March 2015 intensive one day courses were held in Eastern Highlands and Western Highlands provinces providing 51 farmers and 24 Village Extension Workers (VEWs) training in area wide management (AWM) and the biology and ecology of weevils.

Three Kaukau Fact Sheets have been produced by the team:

- Kaukau Fact Sheet 6: Sweetpotato and West Indian kaukau weevils (Appendix 3)
- Kaukau Fact Sheet 7: Wireworms in kaukau (Appendix 4)
- Kaukau Fact Sheet 8: Grow better kaukau planting material (Appendix 5)

In Australia, presentations were made at Australian Sweetpotato Growers Inc. (ASPG) grower field days at Cudgen, New South Wales, and at GRF and Bundaberg.

2.5 An Australian team project review and planning meeting was held at Brisbane on 22 November 2013. Dr Sar from NARI attended this meeting.

In PNG, a project review and planning meeting was held 2 December 2013 in Goroka, EHP. The meeting was attended by representatives from NARI, Fresh Produce Development Agency (FPDA), DAF, VEWs and farmers from EHP and WHP.

2.6 The Australian project team was involved in a teleconference on 24 February 2014 to assist the project SMCN/2012/016 *Review of research needs on natural resource management and crop protection for sweetpotato based cropping systems in PNG*. Later copies of the reviews on the PT trials and sweetpotato weevils were provided to HORT/2014/083 *Developing improved pest management options in support of intensification of sweetpotato production in Papua New Guinea* (proposed) to assist in the development of that proposal. In August 2014 the project findings were presented to members of ACIAR project PC/2010/065 *Integrated crop management strategies for root and tuber crops: strengthening national and regional capacities in Papua New Guinea, Fiji, Samoa, Solomon Islands and Tonga*, which is looking at developing sweetpotato weevil control strategies in PNG and the Pacific Islands. The project results have also been used in the development of project HORT/2014/096 *Supporting commercial sweetpotato production and marketing in the PNG highlands*.

2.7 The prevalence of SPW and WISW throughout the highlands suggests that AWM is the best method of control. Rather than focus on 'white peg' trials the team opted for developing the capacity of VEWs and leading farmers to understand the concept of AWM and for them to introduce the concept to their communities.

Due to staff changes (both project entomologists left at the same time) there was some delay in initiating this work. The originally planned December 2013 training with VEWs had to be delayed until May 2014. Training on AWM was provided to EHP officers in Goroka and Jiwaka, and WHP officers in Mt Hagen. Further courses were run March 2015 providing training to 56 EHP farmers (including 16 VEWs) and 51 Jiwaka and WHP farmers (including 24 VEWs).

7 Key results and discussion

7.1 Viruses

Viruses—Papua New Guinea

The concept of pathogen-tested (PT) sweetpotato was first introduced in 2006 under ACIAR project SMCN/2004/071 and continued under PC/2010/026 and PC/2011/053. Varieties differ in their response to the technology, but yield increases of 25–70% can be expected (Appendix 6). What is not known is how long the PT benefit lasts; finding out was one of the objectives of PC/2011/053.

The projects virus reinfection trials have shown potyviruses *Sweetpotato Feathery Mottle virus* (SPFMV) and *Sweetpotato virus G* (SPVG) to be the most common. SPFMV is found worldwide and is one of the most studied viruses (Moyer and Salazar 1989). It is known to be transmitted in a non-persistent manner by aphids, particularly green peach aphid (*Myzus persicae*), the cotton aphid (*Aphis gossypii*) and possibly other aphids (Clarke and Valverde 2013a). Leaf symptoms may or may not be apparent, depending on the variety and environment. When seen, they consist of irregular chlorotic patterns (feathering) associated with the leaf midribs and/or faint or distinct chlorotic spots that in some varieties have purple pigmented borders. These symptoms are usually observed on the older leaves (Moyer and Salazar 1989; Wosula and Clark 2012). On roots there may be external cracking or internal necrosis. Yield loss due to SPFMV as a single infection can be quite variable with some studies showing little or no yield loss (Clark and Hoy 2006; Wosula and Clark 2012) while others have implicated this virus in causing yield reductions up to 30% (Karyeija *et al.* 1998; Njeru *et al.* 2004; Wang et al. 2010). Varietal resistance may play a role, as may differences in virus titre levels and age of planting material. Other factors may be climatic conditions and there may be some plant reversion to the virus (Gibson and Kreuze 2014). In the Papua New Guinea (PNG) trials variety Sinato Goroka has shown some indication of virus tolerance.

An important aspect of SPFMV is the synergistic interactions it can have with other viruses, in particular *Sweetpotato Chlorotic Stunt virus* (SPCSV). This co-infection is known as *Sweetpotato virus disease* (SPVD) and is currently recognised as the most harmful disease of sweetpotato causing yield declines of 65–90% (Carey *et al.* 1998; Gutierrez *et al.* 2003; Kokkinos and Clark 2006; Untiveros *et al.* 2007).

Unlike SPFMV, SPVG is not well studied. It is similar to SPFMV in that it is common worldwide and transmitted in a non-persistent manner by aphids, particularly green peach and cotton aphid. Plants infected with single infections of SPVG often do not exhibit symptoms and there is thought to be minimal effect of plant yields (Clark and Hoy 2006; Clark *et al.* 2012).

Co-infections of SPVG and SPFMV are common (Clark and Valverde 2013b). Where these co-infections occur 14–18% yield losses have been recorded (Clark and Hoy 2006; Clark et al. 2010). While not as devastating as SPVD, SPVG will synergistically interact with SPCSV causing increased yield losses (Kokkinos and Clark 2006). Wosula *et al.* (2012) found that SPFMV was more readily transmissible from plants with co-infections than single infections.

In reinfection Trial 1, PT planting material had significantly less overall virus infection at harvest than non-PT material (Table 2). This was true for SPFMV and SPFMV+SPVG co-infections. SPVG infection level was low in the trial and differences between treatments were not seen. With a higher level of virus reinfection in Trial 2 there were, no significant differences seen between the type of vine cuttings used, although a trend is seen when looking at the individual varieties (Table 3). In both trials SPFMV was the predominant virus with lower levels of SPVG and SPFMV+SPVG co-infections. This is similar to studies in the USA where SPFMV was also found to be more transmissible than SPVG (Clark *et al.* 2010, Wosula *et al.* 2012, Wosula *et al.* 2013).

Table 2. Virus incidence at harvest in relation to type of planting material used – Reinfection Trial 1

Treatment	Virus incidence	SPFMV incidence	SPVG incidence	Co-infection incidence
PT	0.1875[a]	0.0625[a]	0.1875	0.0625[a]
Non-PT	0.6875[b]	0.6250[b]	0.3125	0.3125[b]
P value	**<0.001**	**<0.001**	**0.201**	**0.044**

Note: 1. Virus presence determined by NCM-ELISA

2. All incidences are reported as proportions

Table 3. Virus incidence at harvest in relation to planting material used and variety – Reinfection Trial 2

Variety and propagation material	SPFMV incidence	SPVG incidence	Co-infection incidence
Beauregard PT	0.2500[ab]	0.0000[a]	0.0000[a]
Beauregard G2	1.0000[c]	1.0000[c]	0.9999[c]
Beauregard non-PT	1.0000[c]	0.5000[abc]	0.5000[ab]
Sinato Goroka PT	0.5000[abc]	0.2500[ab]	0.2500[ab]
Sinato Goroka G2	0.0000[a]	0.0000[a]	0.2500[ab]
Sinato Goroka non-PT	0.7500[bc]	0.50000[abc]	0.5000[ab]
Waghi Besta Minj 2 PT	0.5000[abc]	0.0000[a]	0.0000[a]
Waghi Besta Minj 2 G2	1.0000[c]	0.0000[a]	0.0000[a]
Waghi Besta Minj 2 non-PT	0.7500[bc]	0.7500[bc]	0.7500[bc]
P Value	**0.010**	**0.004**	**0.012**

Note: 1. Virus presence determined by NCM-ELISA

2. All incidences are reported as proportions

The variety Beauregard is known to be sensitive to viruses, as shown in these trials with non-PT planting material having significantly more SPFMV and co-infections. Interestingly, this is not as clear with the PNG varieties. In reinfection Trial 1 variety Sinato Goroka showed significantly less virus infection than the other varieties (Table 4), possibly indicating it may have some tolerance to potyviruses. In reinfection Trial 2 the rate of infection of the PNG varieties was again less than Beauregard. This supports work by Okpul *et al.* (2011) who found a number of PNG sweetpotato varieties showed tolerance to viruses when compared in trials in Australia. It may be that in selecting varieties against yield decline farmers have, unknowingly, chosen varieties that are less sensitive to virus infection.

Table 4. Virus incidence in varieties – Reinfection Trial 1

Cultivar	SPFMV incidence
Beauregard	0.5000[b]
Sinato Goroka	0.0000[a]
Waghi Besta Minj 2	0.3750[b]
Wanmun	0.5000[b]
P value	**0.038**

Note: 1. Virus presence determined by NCM-ELISA

2. All incidences are reported as proportions

In terms of yield, reinfection Trial 1 showed significant yield differences between PT and non-PT planting material (Table 5). In reinfection Trial 2 there was no significant difference between the types of vine cuttings, although there was significant difference when looking at them and variety (Table 6). Beauregard showed significant yield decline with the age of planting material used while the PNG varieties did not show this, further supporting the idea that these varieties, in particular Sinato Goroka, may have some virus tolerance.

Table 5. Storage root yield related to planting material – Reinfection Trial 1

PT Treatment	Root weight per plant (kg)	Market yield (t/ha)	Total storage root yield (t/ha)
Pathogen tested	1.647^{b}	30.1^{b}	33.7^{b}
Non-pathogen tested	1.244^{a}	22.4^{a}	25.5^{a}
P value	**0.005**	**0.012**	**0.005**

Table 6. Storage root yield related to planting material and variety – Reinfection Trial 2

Variety x PT Treatment	Root weight per plant (kg)	Market yield (t/ha)	Total storage root yield (t/ha)
Beauregard PT	1.466^{c}	24.93^{c}	29.92^{c}
Beauregard G2	0.603^{ab}	8.31^{ab}	12.30^{ab}
Beauregard non-PT	0.537^{a}	7.47^{a}	10.95^{a}
Sinato Goroka PT	1.500^{c}	25.84^{c}	30.62^{c}
Sinato Goroka G2	1.379^{c}	24.96^{c}	28.14^{c}
Sinato Goroka non-PT	1.498^{c}	26.55^{c}	30.58^{c}
Waghi Besta Minj 2 PT	1.432^{c}	24.94^{c}	29.05^{c}
Waghi Besta Minj 2 G2	0.950^{b}	16.27^{b}	19.39^{b}
Waghi Besta Minj 2 non-PT	1.479^{c}	27.65^{c}	30.18^{c}
P value	**0.003**	**0.007**	**0.003**

Whether or not the project identified all the sweetpotato viruses in the trials remains to be seen. Indicator plants were also used to assay for virus infection but, although detecting all viruses, they do not allow the identification of individual viruses with certainty. Furthermore, the CIP NCM-ELISA diagnostic kit tests only ten of the most common sweetpotato viruses. Reinfection Trial 2 found two plants that gave positive results on *I. setosa* but were negative with NCM-ELISA. It is possible, therefore, that other viruses—including *Sweetpotato leaf curl virus* (SPLCV), a virus previously reported in the 1980s (Kokoa 2001)—were present. Samples of the two plants have been sent to Secretariat of the Pacific Community (SPC) for PCR diagnosis. Arrangements are also underway to send the samples to Australia for qPCR diagnosis and to CIP for verification.

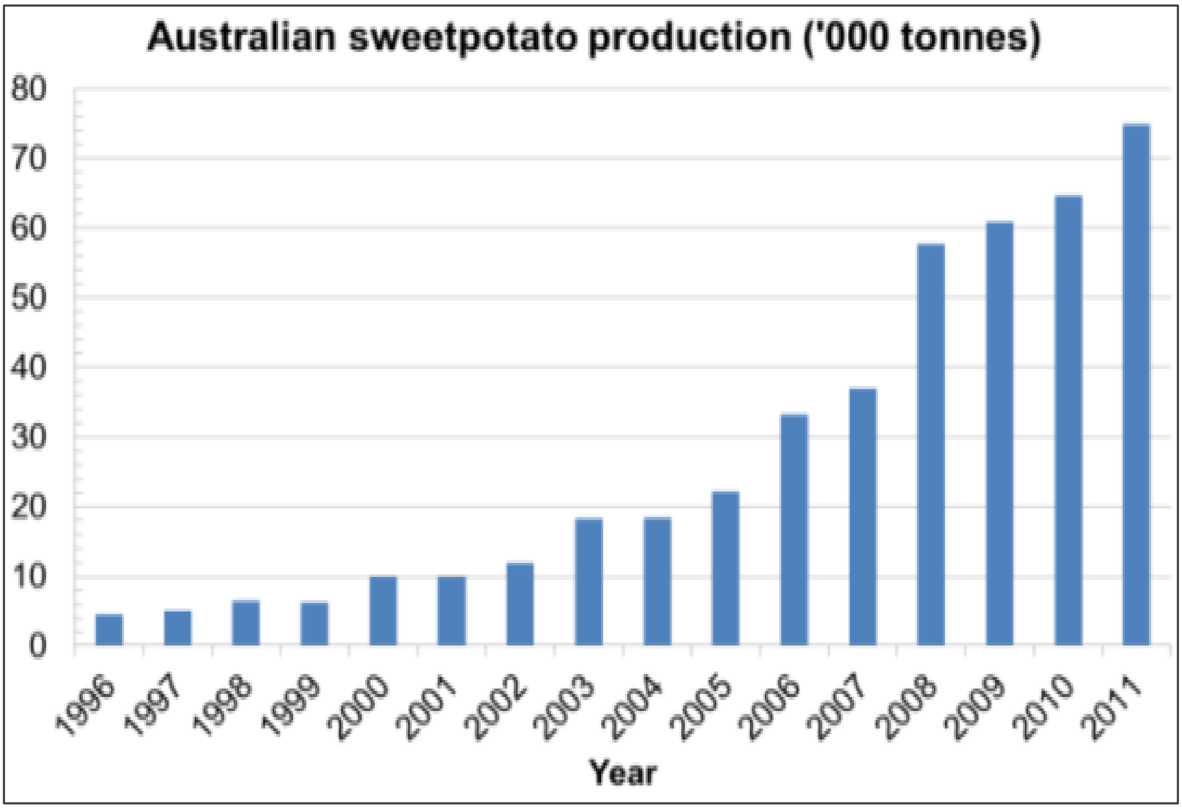
The NCM-ELISA tests also gave indeterminate readings for *Sweetpotato chlorotic fleck virus* (SPCFV), SPCSV and *Sweetpotato mild speckling virus* (SPMSV). SPCFV was confirmed in PNG in 2008 (Coleman *et al.* 2009). Elsewhere, SPCFV has been transmitted mechanically but its vectors, if any, are unknown. The plants suspected of having SPCSV and SPMSV will be retested.

Viruses—Australia

The use of PT planting material by Australian sweetpotato growers has been instrumental in the industry's growth in recent years (Figure 1). Yields have improved significantly as a result of the reduction of unmarketable storage roots (E Coleman, Australian Sweetpotato

Growers Inc. (ASPG) Secretary, *pers. comm.* 2014). There is now interest in having a better understanding of the viruses that are in Australia and the potential risks that they present, as well as any different viruses in nearby countries. This project has enabled the development of an improved virus diagnostic capacity, ensuring farmers receive the best quality planting material.

Figure 1. Australian sweetpotato production 1996–2011



Prior to this project, the major diagnostic tools in use by the Australian sweetpotato industry and associated researchers were:

- Herbaceous indexing with *Ipomoea setosa*; excellent for indicating the presence of viruses, not for specific identifications.
- NCM-ELISA for the ten most common sweetpotato viruses (*C-6 virus*, *Cucumber mosaic virus*, *Sweetpotato Caulimo-like virus*, *Sweetpotato chlorotic fleck virus*, *Sweetpotato chlorotic stunt virus*, *Sweetpotato feathery mottle virus*, *Sweetpotato latent virus*, *Sweetpotato mild mottling virus*, *Sweetpotato mild speckling virus* and *Sweetpotato virus G*). To date the CIP NCM-ELISA kit is unable to indicate begomoviruses or phytoplasmas.

In 2014 the project enabled development of real time-PCR (qPCR) to assist in identification of viruses not identifiable by NCM-ELISA, in particular those that *I. setosa* had indicated a virus presence of. So far, qPCR has confirmed the presence of the begomovirus SPLCV in Bundaberg, Cudgen, Lockyer Valley, Mareeba and Rockhampton, the major sweetpotato production areas of Australia. Isolates of SPLCV are currently being sequenced and characterised, with further work planned depending on the results obtained.

SPLCV is believed to be widespread worldwide and is transmitted by the whitefly *Bemisia tabaci* (Simmons *et al.* 2009). Upward leaf curling symptoms may develop in some sensitive varieties when environmental conditions are suitable. These may be transient, with plants recovering quickly (Kokkinos 2006). Storage roots affected with SPLCV may exhibit shallow, longitudinal grooving and darkening of the skin (Clark and Hoy 2006). Sweetpotato yield losses associated with SPLCV may be 24–50% (Clark and Hoy 2006; Kokkinos 2006; Simmons *et al.* 2009), although it is not believed Australian farmers are suffering losses such as these, possibly due to the fact that a high proportion of the industry are regularly replenishing their planting stock with PT material.

Currently, qPCR capacity is being used to test for begomovirus, *Ipomoea vein mosaic virus* (IVMV), SPCSV, SPFMV, SPLCV and SPVG.

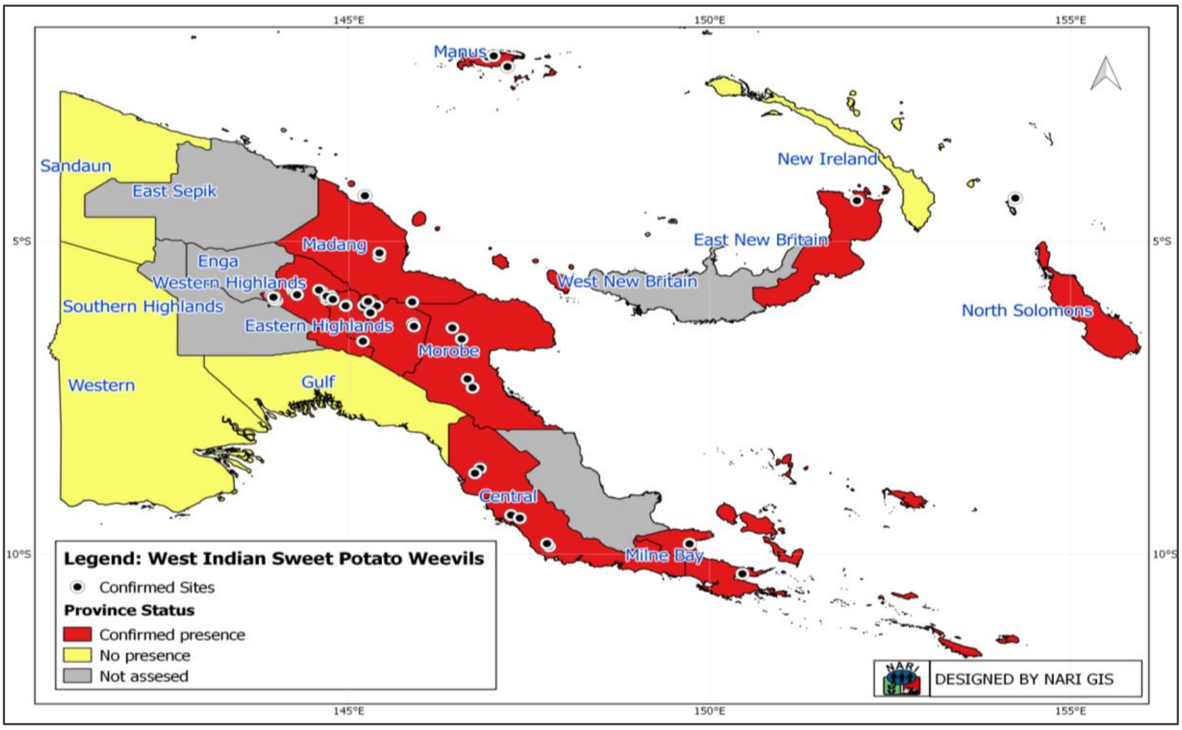
7.2 Sweetpotato weevils

Weevil studies

Previous ACIAR funded project SMCN/2004/071 *Reducing pest and disease impact on yield in selected PNG sweetpotato production systems* identified that in addition to the sweetpotato weevil *Cylas formicarius* (SPW) a second sweetpotato weevil, West Indian sweetpotato weevil (*Euscepes batatae*) (WISW) (previously *E. postfasciatus*), is present in PNG. Both weevils are beetles but belong to different taxonomic families: SPW belongs to the family Brentidae, commonly referred to as 'straight-snouted weevils', and WISW belongs to the family Curculionidae or 'true weevils'.

At the time of discovery it was thought WISW may be restricted to the Aiyura valley where it was first found. As part of this project 150 localities have been surveyed. The result is that WISW is widespread and well established throughout the country (Figure 2). Despite having wings WISW is not known to fly (Alleyne 1982; Moriya and Miyatake 2001) and Japanese field studies have shown that it only walks short distances, 5–7 metres per day (Kinjo *et al.* 1995; Kumano *et al.* 2009), so presumably WISW has been distributed with movement of storage roots and planting materials.

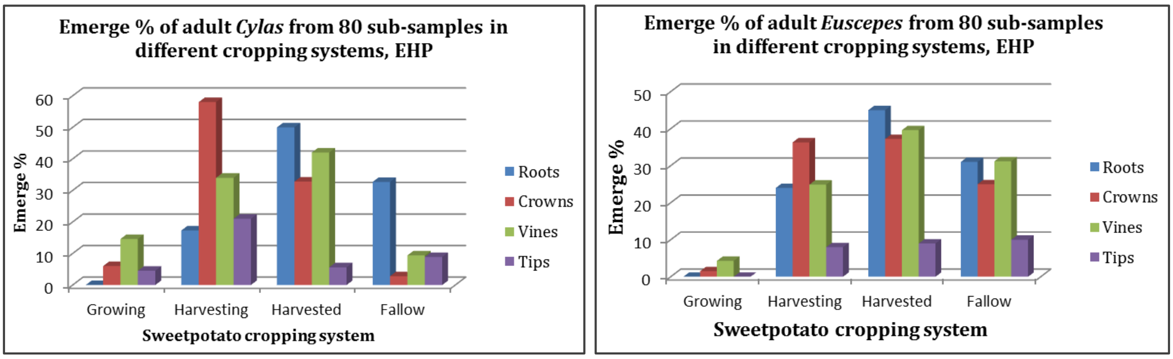
Figure 2. Known distribution of West Indian Sweetpotato weevil (*Euscepes batatae*) in PNG



WISW was found to be active at higher altitudes than SPW, being discovered on a number of farms at 2300 m above sea level, well above the (approximate) 1800 m above sea level figure for SPW. At altitudes suitable for both weevils, SPW and WISW were seen cohabiting in storage roots, crowns and stems. In these situations WISW is generally found in greater numbers than SPW.

Rearing studies, relating the presence of weevils to growth of the crop, showed the highest level of SPW occurred during crop maturity when it is ready for harvest and the level then declines after harvest, as might be expected (Figure 3a). Roots, crowns and stems were all favoured feeding sites. WISW followed a similar pattern of infestation, with the exception that the weevils tended to remain at the crop site during the fallow phase, feeding on whatever residues are left from the harvest (Figure 3b). It is possible their lack of flight mobility reduces the desire to source new food sources until necessary.

Figure 3a & b. Sweetpotato weevil prevalence during different crop stages



Note: Harvesting = when the crops is ready for the first harvest.

Harvested = from 1st to last harvest

Fallow = weevil found in residues left in the field after harvest is completed

During the project, with the assistance of visiting scientists, the project team developed a key to differentiate the larvae of the SPW and WISW (Table 7).

Table 7. Characteristics of *Cylas formicarius* and *Euscepes batatae* larvae

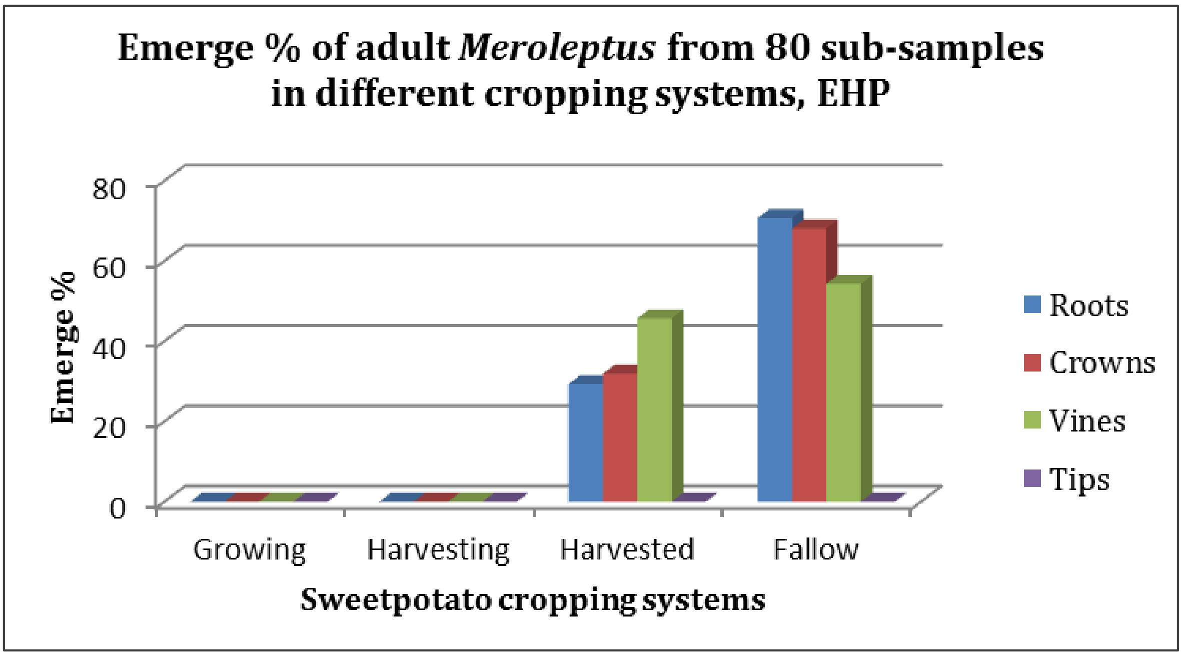
Character	*Cylas formicarius*	*Euscepes batatae*
Frontal suture	Reaching mandibular base	Not reaching mandibular base
Antennae	Separated from frontal suture Much larger than eye spot	Attached to frontal suture About size of eye spot
Basal abdominal segments (larval stage)	With two dorsal folds Abdominal segments are smooth on the surface	With three dorsal folds Abdominal segments are quite rough on the surface
Upper row of vertical setae	Outer setae posterior to inner setae	Outer setae anterior to inner setae
Facial setae	Shorter	Longer
General appearance of larvae	Much whiter in colour in all stages Smaller in size	Pale brownish white colour in all stages Larger in size

In late 2014 it was realised that there was a third weevil attacking sweetpotatoes. While the identity is not yet authenticated it appears to be *Meroleptus cf. cinctus* (Marshall 1959), coffee ring borer (CRB). There is minimal information available on CRB. It is listed in Papuan

Curculionoidea, Zootaxa 1536 (2007) as having been recorded in Goroka, PNG and Jayapura, West Papua. Ghauri (1964) noted it as a pest of coffee in Aiyura, EHP and Simbiken (2006) and states that farmers in Boana district, Morobe Province believed it to be a major coffee pest, but also said it does not warrant control measures. Yaku (1992) identified it as attacking sweetpotato stems but made no mention of it eating leaves or infesting storage roots. French (2006) mentions that it is an occasional pest of strawberry without saying where.

CRB was found throughout EHP, but none were collected from other provinces. It was only found in crops where sequential harvesting had been initiated and roots yet to be harvested were exposed, or in fallow land where there were residue plants (Figure 4). Further work is needed to determine the association of this weevil to sweetpotato. 'Is it a main host?' or 'Is infestation influenced by the proximity of coffee plants?' are research questions that need to be answered.

Figure 4. Prevalence of *Meroleptus cf. cinctus* during different stages of sweetpotato



Note: Harvesting = when the crops is ready for the first harvest.

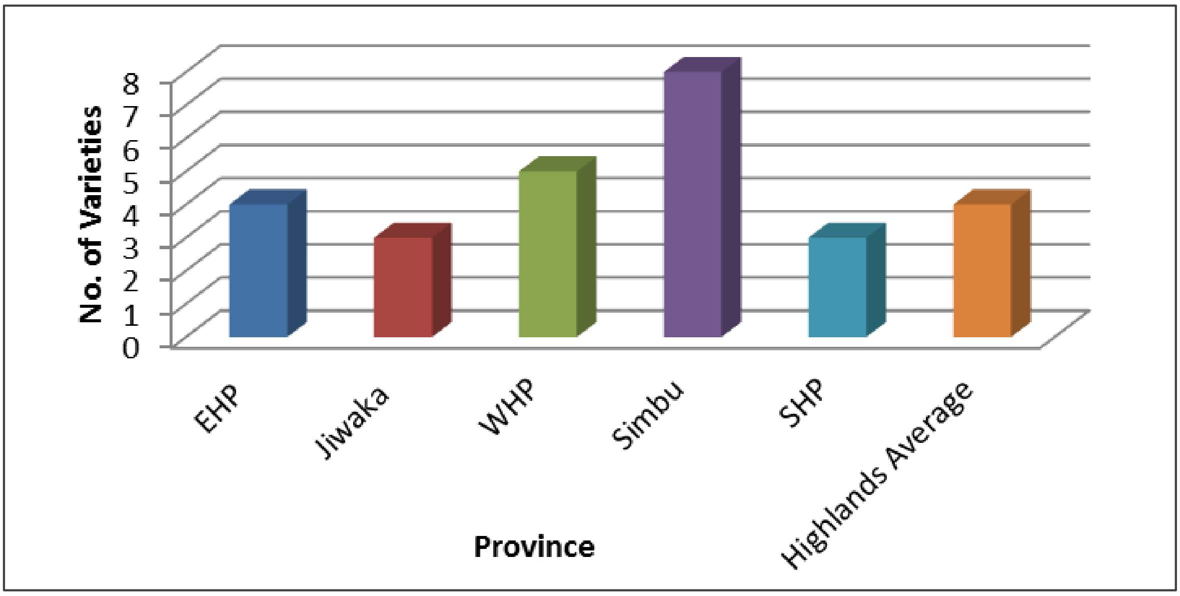
Harvested = from 1st to last harvest

Fallow = weevil found in residues left in the field after harvest is completed

Sweetpotato grower knowledge survey

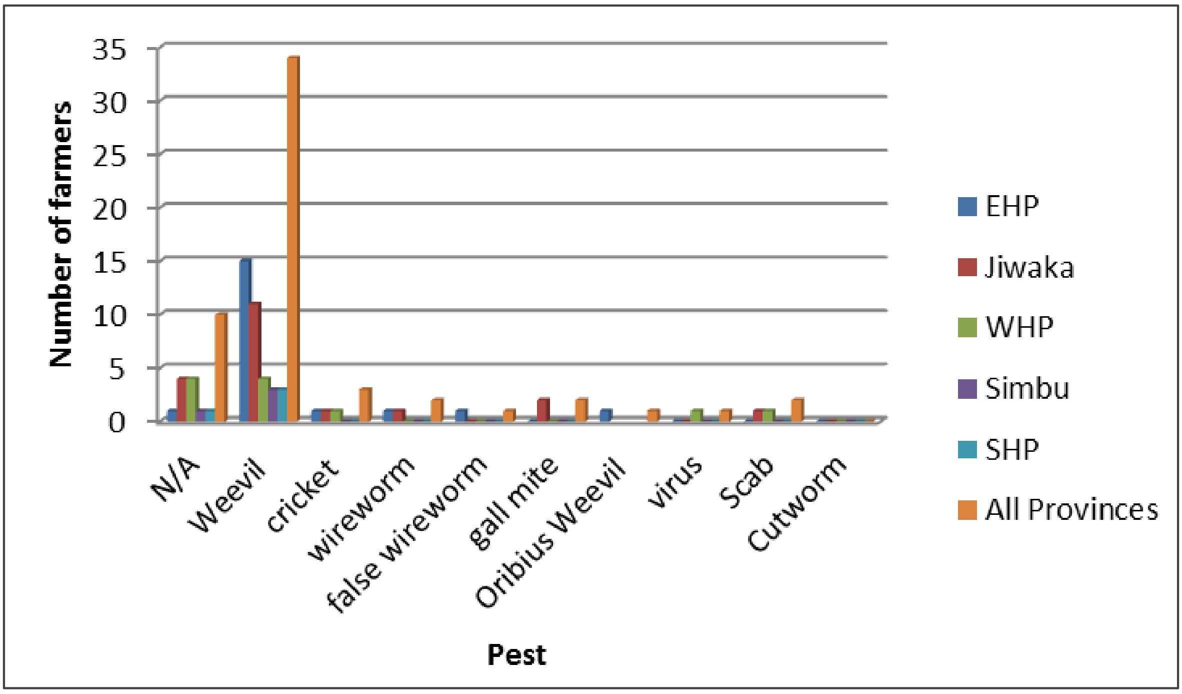
To better comprehend farmers' knowledge of sweetpotato weevils, 50 sweetpotato growers were surveyed throughout the highlands: Eastern Highlands Province (EHP) (19), Jiwaka Province (16), Western Highlands Province (WHP) (10), Simbu Province (4) and Southern Highlands Province (SHP) (1). These consisted of subsistence growers (28), commercial sweetpotato producers (20), and school garden managers (2). On average farmers grew four sweetpotato varieties (Figure 5), with subsistence farmers growing more than those growing for market. Except for one subsistence farmer in Simbu, who grew 20 varieties, all the others grew 10 or less, with three farmers growing only a single variety. The main varieties grown were Wahgi Besta, Sinato, Rachel, Wanmun and Grace.

Figure 5. Average number of sweetpotato varieties grown by farmers



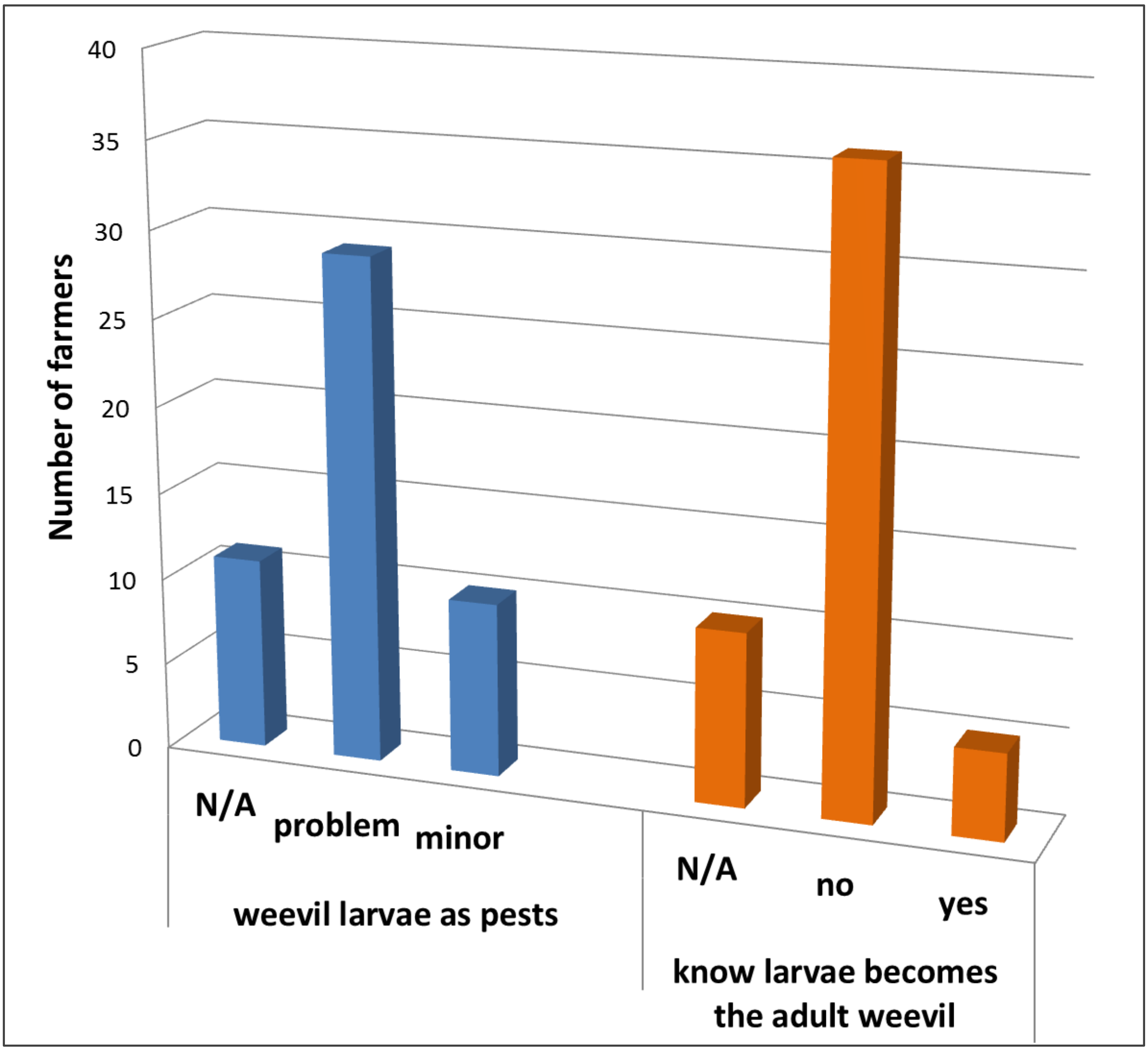
The results of these surveys showed that PNG highland farmers are aware of the damage done to storage roots, clearly ranking weevil damage as the issue of greatest concern (Figure 6), particularly in dry periods.

Figure 6. Sweetpotato pest problems identified by PNG highland farmers



Further questioning revealed that most farmers have no understanding of SPW or WISW lifecycles or that the larvae are related to adult weevils (Figure 7). On more than one occasion during the surveys farmers said they believed the larvae were the adult stage and came from the soil. Seventy-two per cent did not know of the relationship between larva and adult and 44% did not know how the weevils came into their crops. As the larvae of both species are whitish, curved and without legs, it is not surprising that farmers do not identify them as being different pest species.

Figure 7. Farmer knowledge of weevil larvae as a pest, and its life stages



Farmers were asked about weevil resistant varieties and only two farmers knew of one. A grower in a high altitude area above where SPW is found had heard of a variety but could not recall its name or where it was and a grower in EHP said he knew of a variety 'Ingiso' that was resistant to weevils. In the previous project SMCN/2004/071, a farmer at 5 mile near Kainantu told the author of a variety that he had that was resistant to weevils, but he only grew it as an emergency food source because it tasted terrible!

Given the response from farmers about weevil tolerant varieties there is probably little to be gained from efforts to breed for resistance. After all, the farmers hold PNG's greatest gene pool, and are likely to have tested hundreds if not thousands of varieties and found little or nothing that is acceptable. This conclusion is backed by the Asian Vegetable Research and Development Centre (AVRDC) that spent 14 years unsuccessfully screening 1200 sweetpotato varieties for sweetpotato weevil resistance (Talekar 1989).

When asked if they are doing anything to control weevils only 6% of growers said they are doing anything, but on further questioning 30% were found to be hilling up the crop, which covers any soil cracks that would allow weevils to reach the storage roots. Plant mulches are also used: *Piper aduncum* and silver leaf desmodium were mentioned by a number of Jiwaka growers and one farmer used wild Mexican sunflower (*Tithonia diversifolia*).

Two commercial farmers in EHP told how they were having success using red ants to control weevils. These had been transported from Madang Province. The farmers stated that these ants did not have any association with green coffee scale.

Only two farmers used insecticides to control weevils—one would dip cuttings before planting and one would apply an over-the-crop spray when he felt it was required. One grower stated that rotation was an important aspect of controlling weevils, while another told how she uses PT material that she knows is free of weevil and, as it matures earlier, it does not suffer as much weevil damage.

This survey highlighted that although sweetpotato weevil damage is of great concern to farmers the farming community has very little knowledge of these pests. This is more than likely related to the fact that 56% of the farmers receive no agricultural information. Thirty-four per cent obtain information from National Agricultural Research Institute (NARI) or Fresh Produce Development Agency (FPDA) or both, while non-government organisations (NGOs), relatives, friends and in some cases the local pastor play a lesser role in providing information. Most of the surveyed farmers indicated a preference of learning by participating in projects, farm visits from agricultural agencies, or attending workshops, over more passive forms such as radio, literature and DVDs. Interestingly, two growers suggested that they would like to obtain information via their mobile phones.

Area wide management (AWM)

Although PNG has at least 28 host plants for SPW and nine for WISW (Appendix 7), it is likely that sweetpotato residues and volunteer plants sustain weevil populations between crops of sweetpotato. The vines and storage roots left from harvests and feral plants can be found around every garden, along roadsides and in land left to fallow. Given the ample amount of food sources available, it will not be possible to eradicate sweetpotato weevils; therefore, the appropriate focus should be on managing the farming system to minimise the effect of weevils in the sweetpotato crop. For numerous reasons—including cost, availability, operator and consumer health, and safety and environmental concerns—a simple chemical based strategy is not suitable for PNG. A strategy that integrates a number of management practices to control weevils at either farm or, preferably, village level is a more suitable control option.

Studies in Australia (Russell McCrystal *pers. comm.* 2014), and the sweetpotato surveys reported herein, indicate that weevil build-up is highest when there are mature roots and residues available as a food supply. Removal of these food sources is a critical step in reducing weevil populations. This means that harvested vines and discarded storage roots will need to be appropriately disposed of; this in turn will mean that farmers will take their terminal vine cuttings for replanting from young crops or from plants grown in nurseries, ideally sourced from PT stocks. In either case, more vigorous, earlier maturing and weevil-free propagating material can be expected.

As both SPW and WISW are specific to Convolvulaceae, the use of crop rotations is another way to reduce weevil populations. Male SPW are attracted to a sex pheromone ((Z)-3-dodecen-1-ol(E)-2-butenoate) that can be synthetically reproduced. Both this and the previous project have shown pheromone lures work well in the PNG environment. When used in conjunction with other management strategies, pheromone lures in simple traps made from plastic bottles may reduce the effects of SPW re-infestations. Currently the feeling is that pheromone lures are difficult to obtain and would be expensive for PNG farmers, but that might change if the technology is used extensively. While there is no similar attractant for WISW the weevils are not known to fly and do not tend to move great distances, so they may be more easily managed if their food source is removed.

In 2014 and 2015, intensive one-day courses were held in Eastern Highlands and Western Highlands provinces. Farmers and Village Extension Workers (VEWs) were given training in AWM concepts, the biology and ecology of weevils, and management strategies for their control.

The principles workshopped were:

1. Crop hygiene—removal of sweetpotato residues
    a) Old vines
    b) Old roots
2. Removal of alternate hosts
3. Crop rotation
4. Selection of short duration varieties when growing into expected periods of weevil infestation
5. Propagation from PT material where possible (clean of weevils and eggs, early maturing)
6. Propagation from seedbeds rather than old vines in fields
7. Propagation from vine tips rather than back cuttings
8. Use insecticide dips before planting vines or treating nurseries (included appropriate OH&S)
9. Personal hygiene, e.g. not carrying weevils in on clothes
10. Deeper planting of vines
11. Reducing cracks in soil
    a) Keeping soil moist (currently there is minimal, if any, sweetpotato irrigation in PNG)
    b) Hilling up
    c) Mulches
12. Single harvest at crop maturity rather than multiple harvests (Note: PT material will reduce time to harvest)

Discussions were also held around the practice of some EHP farmers introducing ants to control weevils, and some other potential weevil control measures such as entomopathogenic fungi (*Beauveria bassiana*), samples of which showed strong pathogenicity in laboratory trials in project SMCN/2004/071. However, although of interest, it is not a practical treatment that can be recommended.

These initial training sessions were keenly received by both the commercial farmers and VEWs who attended. Interestingly the commercial growers, who one might expect may keep this learning to themselves for business advantage, have in fact been some of the keenest to extend the knowledge to their fellow farmers. There is a need to focus further on this type of training, targeting both commercial farmers, village extension agents and farming community leaders if the AWM concept is to be developed and championed by the farming community.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Viruses

Viruses feature strongly in yield decline of sweetpotato and this project has established that given suitable vector conditions reinfection can begin within the first generation of pathogen-tested (PT) crops, and increase with successive generations. To date, the NCM-ELISA has shown that potyviruses, *Sweetpotato feathery mottle virus* (SPFMV) and *Sweetpotato virus G* (SPVG) are common, with SPFMV possibly being more readily transmissible than SPVG. Co-infections of these viruses are also common.

This and previous projects have shown differences between PT and non-PT planting material, indicating that viruses do have an effect on sweetpotato crops. In this project the Papua New Guinean commercial varieties, in particular Sinato Goroka, appear to show a level of tolerance to these potyviruses, both in reinfection rate and in the effect on yield. Consequently, these varieties may take longer for single or multiple potyvirus infections to cause yield decline. Such varieties could be the backbone of a 'clean seed' scheme in Papua New Guinea (PNG), enabling farmers to improve productivity without expanding garden size or increasing labour inputs.

The project showed that other viruses may infect sweetpotatoes—*Sweetpotato chlorotic fleck virus* (SPCFV), *Sweetpotato chlorotic stunt virus* (SPCSV) and *Sweetpotato mild speckling virus* (SPMSV)—although retesting is required. A positive result for SPCFV will be a reconfirmation of the 2008 finding by Takaboi (Coleman *et al.* 2009), whereas positives for SPMSV and SPCSV would be new findings for PNG. Indexing onto indicator plants has suggested that there may be a begomovirus present, which cannot currently be determined by NCM-ELISA. Again, further testing may re-confirm the presence of *Sweetpotato leaf curl virus* (SPLCV), a begomovirus last found in the 1980s, or the presence of a new virus.

During the next five years more sweetpotato virus diagnostic technologies will become available. National Agricultural Research Institute (NARI) currently has PCR capability and is looking at obtaining sweetpotato primers. Loop-mediated isothermal amplification (LAMP) technology is being brought to PNG as part of the ACIAR funded project HORT/2012/087 *Bogia Coconut Syndrome in Papua New Guinea and related phytoplasma syndromes: Developing biological knowledge and a risk management strategy*. Currently, the International Potato Center (CIP) is developing protocols on the use of LAMP in diagnosing sweetpotato viruses. It is envisioned that as these protocols become available it will be used for sweetpotato virus diagnosis in PNG.

It is expected that within the next five years PNG will have established an accurate country record of viruses affecting sweetpotato.

Although Secretariat of the Pacific Community (SPC) has PCR capability it has only recently used it for sweetpotato diagnostics. However, PCR alone without a complete range of primers will not confirm the presence of viruses. Similarly, NCM-ELISA is a valuable tool for identifying the world's ten most common sweetpotato viruses, but cannot identify begomoviruses. Plant indexing is important in that it will identify the presence or absence of viruses, the identity of which can then be established by other techniques. During the project SPC has introduced *I. setosa*, but to date has not had success in indexing. This should change as staff skills in this process develop. As a repository for sweetpotato germplasm and a distribution centre to Pacific Island nations, there will be increasing pressure on SPC to ensure the quality of distributed germplasm is of the highest standard.

In Australia the introduction of qPCR has enabled the industry to identify SPLCV as a new virus. This is an important find as synergism between SPLCV and SPFMV increases yield loss, particularly in variety Beauregard the current industry standard. Additionally, the industry now has the ability to check for *Ipomoea vein mosaic virus* (IVMV) and reconfirm SPCSV, SPFMV and SPVG. This capacity will increase the knowledge of sweetpotato viruses in Australia and continue to improve the quality of the already world-leading PT seed scheme.

Regionally, improved virus diagnostics will result in better quality PT planting material being made available to researchers. This, combined with the *Checklist for conducting sweetpotato trials* (Appendix 8) developed as part of the project, will improve future sweetpotato research trials. Collaborative workshops in Fiji and Australia have enabled the project scientists to standardise their diagnostic protocols, giving further confidence in the results obtained.

Sweetpotato weevils

For a number of years PNG researchers have recognised sweetpotato weevil (*Cylas formicarius*) (SPW) as the main pest of sweetpotatoes. When West Indian sweetpotato weevil (*Euscepes batatae*) (WISW) was identified it was thought to be confined to the Aiyura Valley. Now it is known throughout the country and may be a more important pest than SPW. WISW infests sweetpotato at 2300 m above sea level (asl), well above the altitudes where SPW is found.

Previously, there was minimal knowledge available to differentiate SPW and WISW larvae, requiring researchers to rear the larvae to determine the species. The project developed a key to identify the weevils from their larval characteristics, greatly reducing the time now required to determine the species collected.

Due to the prevalence of alternate hosts, in particular feral sweetpotato, it is clear that elimination of sweetpotato weevils is not feasible. Area wide management (AWM) has been determined as the best strategy for sweetpotato weevil control. If adopted by farmers and implemented at village level, it is likely to reduce the numbers of both species. An important component of AWM will be the use of PT planting material, as it should be free of weevil eggs, apart from having agronomic advantages.

During the project there have been some discussions as to the potential for developing a PT 'seed' scheme at Highlands Regional Centre (HRC), Tambul (2300 m asl), due to the low incidence of virus vectors at this high altitude centre. Although WISW was not found in any trial sites in the centre it was found in bordering gardens, indicating management strategies for this pest will have to be developed to keep the production areas free of this pest.

Currently WISW is not known to be in Australia and, as a result of these studies, requests have been made to the Northern Australian Quarantine Strategy (NAQS) to add WISW to their list of insects of concern.

8.2 Capacity impacts – now and in 5 years

Due to a number of unforeseen staff changes most of the scientists in PNG were new to researching sweetpotato. Training courses in Fiji and Australia, combined with the project work, have seen these researchers become competent in virus identification using indicator plants and NCM-ELISA. The training provided by Dr Segundo Fuentes (CIP), and funding assistance by the Crawford Fund, has introduced these scientists to new diagnostic methods (e.g. LAMP, qPCR and microarrays). LAMP technology will be used in PNG in ACIAR funded project HORT/2012/087, so it may be available for sweetpotato virus studies within the next five years.

The project, through training and its communication strategies, has enabled the researchers to develop professional networks. The project officers continue regular communications amongst each other and CIP, further developing their skills. Myla Deros has travelled to Solomon Islands to train 12 officers in the use of NCM-ELISA and to virus index 18 Solomon Island sweetpotato varieties. Dorcas Homare is utilising skills and knowledge, gained from this and the previous projects, in ACIAR project PC/2010/065. Wilfred Wau (sponsored by Crawford Fund) has organised training in using indicator plants and NCM-ELISA for officers from Vanuatu, Solomon Islands and NARI. Within PNG Winnie Maso and Myla Deros have provided training in sweetpotato virology to staff from NARI, Fresh Produce Development Agency (FPDA) Coffee Industry Corporation (CIC) and Unitech.

Staff from SPC have been working collaboratively with Australia project officers in developing the capacity to utilise qPCR, ready for such time as it may be introduced to SPC.

Apart from the impact of viruses, the project has also been concerned with agronomy of the crop. It realises that conditions during the first few days are critical for storage root development. In order to promote best practices for sweetpotato trials, as well as extension training, the project has produced a set of guidelines (Appendix 8).

At project initiation staff had minimal knowledge of sweetpotato weevils in PNG. Team members have developed protocols to better understand these pests and how they can be managed. They have also developed taxonomic skills to identify SPW and WISW larvae.

Thecla Guaf has transferred the skills she has developed in sweetpotato weevil identification and AWM to Solomon Islands, as well as informing other Pacific Island scientists as part of the ACIAR project PC/2010/065. Anna Kawi is utilising knowledge she developed in her new role with National Agricultural Quarantine and Inspection Authority (NAQIA), continuing to update the country's knowledge of the distribution of WISW.

As AWM is the preferred control method for sweetpotato weevils, project staff have had to hone their knowledge and skills in extension to ensure farmers and agricultural officers are aware of the pest and why the chosen method is preferred and to encourage extension staff and farmers to develop their own on-farm protocols.

8.3 Community impacts – now and in 5 years

Viruses/PT sweetpotato

To date PT technology has generally remained in the realms of researchers, development agencies and their Village Extension Workers (VEWs) or farmer co-operators; it has not been extended to farmers, except occasionally at field days, agricultural shows and fairs, and workshops. During 2013 and 2014, 1240 PT vine cuttings were distributed by NARI to FPDA through an EU-ARD project *Generation and adaptation of improved agricultural technologies to mitigate climate-change imposed risks to food production within vulnerable smallholder farming communities in Western Pacific Countries*.

Responses by those who have used PT plants have been very positive. One commercial farmer near Mt Hagen was able to secure contracts to supply a food distribution agent as his PT planting material produced storage roots of better shape and quality. Agnes Jonah, a commercial farmer near Minj, developed her sweetpotato production and marketing strategy around her ability to provide PT planting material to satellite farmers. The higher quality storage roots produced enable these farmers to either sell at higher prices or, when markets are oversupplied, sell first, as their roots are preferred by the customers. Goli, another farmer in Minj, told of how she was able to obtain a K15.00 per 80 kg bag price premium for PT storage roots at Kundiawa market. A VEW from Tari multiplied and planted PT material he obtained from the VEW's induction course in Mt Hagen and made K2,000.

All of these growers tell of gaining higher yields from using PT cuttings and having less sweetpotato weevil problems. Agnes Jonah conducted her own studies on yield decline of PT variety Whagi Besta, and believes that on the flat land around Minj crops are lasting six cycles before needing replacement, while in the poorer soils in the surrounding hills this drops to four cycles.

It is now not uncommon for commercial growers to pay cash for PT planting material and, in some cases contract other farmers to produce it for them. Agnes Jonah has been developing her business by selling PT vines to local farmers, farmers from other provinces, and politicians or political aspirants wanting to assist farmers. Although not yet strongly promoted, growers, particularly from the commercial sector, have seen the benefits of using PT planting material and are asking for it. It is now the opportune time to establish a clean planting material program to ensure the farming community as a whole can benefit from the advantages of PT, which in turn will enable consumers access to better quality storage roots.

The widespread use of PT planting material will reduce the need for farmers to clear new ground, or in highly populated regions allow better productivity of the scarce land available.

Sweetpotato weevils

With the exception of the damage they cause, farmers currently have little or no knowledge of sweetpotato weevils, the most important insect pest of the crop. The project has instigated a process for developing community awareness of weevils and has championed a way to manage the pests. As the project team has been working with leading farmers and VEWs it is expected that this information will be conveyed further into their local communities. Should this process be further expanded, there is the opportunity to reduce further the incidence of SPW, WISW and *Meroleptus cf. cinctus* (coffee ring borer) (CRB).

8.3.1 Economic impacts

The trials in this project showed wide variation in yield from PT and non-PT materials. Reinfection Trial 1 showed statistical difference between PT and non-PT planting material. Reinfection Trial 2 showed different results, with only Beauregard showing a statistical yield difference, indicating that either PNG varieties may have some tolerance to viruses or there may be other environmental or agronomic factors affecting yields. Based on previous studies, there is a yield benefit of about seven tonnes per hectare when using PT materials. Should a clean planting material scheme materialise, commercial growers using PT planting material can be assured of a substantial economic gain.

8.3.2 Social impacts

PT planting material of PNG commercial varieties has been made available to some farmer co-operators since 2011 under ACIAR project PC/2010/026. Agnes Jonah, one of the VEW/farmer co-operators with this (PC/2011/053) and the previous projects, has been producing PT material in her two small PT screenhouses and growing on, giving out, or selling the vines. From her experience, she believes PT material will out yield non-PT for up to six generations on her farm, and four generations on the higher slopes. She also believes that the sweetpotato weevil problem is less when she uses PT material. This is due to the fact she is not transferring weevils to the field in cuttings and PT planting material grows faster so she can harvest earlier, before weevil populations become a problem. From the sales of her PT produced roots and sales of PT vine she has made enough money to build herself a house made from permanent materials (Figure 8).

In EHP Aku Kulo, a commercial sweetpotato grower, has also been using PT sweetpotato planting material since 2011, and is a strong advocate of it. He has credited PT planting material assisting him to purchase a Public Motor Vehicle (PMV) bus (Figure 9).

Should PT planting material become more available to farmers, some of the advantages that have been enjoyed by these innovative farmers will be available to many more.

At the subsistence level, gardening is often a communal activity, with men involved in the construction of the gardens and women looking after the growing and harvesting. As less land is required for the same level of production this will allow more time for other social or business activities.

Figure 8. Agnes Jonah (right) with her mother (left) in front of the house she built from the proceeds of growing and selling PT roots and PT vines

Figure 9. Aku Kulo with the bus he bought from sales of sweetpotato grown from PT cuttings

8.3.3 Environmental impacts

Sweetpotato is the most important crop in PNG, with increasing demand due to economic growth and increasing urbanisation in coastal cities such as Lae and Port Moresby (Chang 2015). To meet this demand growers will continue to commercialise their production, and pests and diseases will increasingly threaten production. The use of PT planting material to reduce the effects of viruses and AWM to manage sweetpotato weevils and other pests such as CRB, will need to be developed to prevent farmers using alterative solutions such as insecticides.

Obtaining higher yield by using PT material may also result in less need to clear new land for gardens.

8.4 Communication and dissemination activities

- Presentations made to 60 farmers at Farmers Collaboration Field Day held in Anamumampa, Gadsup/Tairora LLG in Kainantu District, July 2013
- Project posters, samples and specimens were displayed and presentations made to 50 Unitech agriculture students visiting HRC Aiyura
- Project display was manned at NARI Innovation Show, 27 June 2013
- Project display was manned at the Goroka show, 13–16 September. 30 Kaukau Fact Sheets were provided to motivated farmers
- Project displays were manned at the Kainantu Agricultural Show, 25–29 November 2013
- Presentations made to students from Kainantu Technical Secondary School
- Presentations made to 14 students from SIL LLEAD visiting HRC Aiyura
- Presentation to sweetpotato farmers and agribusiness at Cudgen, NSW, 19 August 2014
- Sweetpotato weevils in PNG presentation to ACIAR project PC/2010/090, 29 August 2014
- Update of project ACIAR PC/2011/053: I*dentifying appropriate strategies for reducing virus and weevil losses in sweetpotato production systems in Papua New Guinea and Australia* to ASPG and sweetpotato farmers attending the sweetpotato field day at Gatton Research Facility, Queensland, 13 November 2014
- News article: *Sweetpotato Virus Diagnostics Workshop*, July 2015 http://www.crawfordfund.org/news/news-sweetpotato-virus-diagnostics-july-2015/

Training activities

Workshops

- SPC CePaCT – Sweetpotato virus indexing (including PCR application), 26–30 August 2013. NARI, DAF, ASPG, SPC and consultant Grahame Jackson participated
- Pathogen-tested (PT) sweetpotato and sweetpotato weevil training, 3–12 December. Gatton, Rockhampton and Bundaberg, Queensland. A Mararuai and A Kawi.
- Sweetpotato weevil and PT sweetpotato workshop, 20 May 2014. Lutheran Guesthouse, Mt Hagen, WHP. Eight participants (VEWs, lead farmers, FPDA)
- Sweetpotato weevil and PT sweetpotato workshop, 23 May 2014. Department of Agriculture and Livestock (DAL) conference room, Goroka, EHP. 12 participants (VEWs, lead farmers, Oxfam, DAL)
- Sweetpotato virus diagnostic workshop, 10–19 November 2014. Gatton Research Facility (GRF) and Rockhampton, Queensland. Attended by CIP, NARI, SPC and DAF. The Crawford Fund sponsored two NARI scientists to attend this workshop

- Sweetpotato weevil and PT sweetpotato workshops, 23–27 March 2015. Participants in EHP (56 farmers including 16 VEWs) and WHP/Jiwaka (51 farmers including 24 VEWs)

Other training

- HRC Aiyura—ELISA training, 7–14 July 2013. For Michelle (Coffee Industry Corporation) and Wilfred Wau (EU ARD project technician, NARI Bubia)
- HRC Aiyura—Sweetpotato PT training and sweetpotato weevil training, 2–6 September 2013. For Kelly Moe, Zure Wahasoka, Jepheth George and David Arre, students at University of Goroka
- HRC Aiyura—Sweetpotato PT training and sweetpotato weevil training – industrial placement, 2013. For Melanie Pitiki, Unitech Agriculture student
- GRF—Herbaceous indexing using *Ipomoea setosa* training, November 2013. For Emma Coleman, University of Queensland agriculture student
- Pathogen Testing of sweetpotato training, 19–22 May 2014. For Rachel Langenbaker and Emma Coleman
- GRF—Pathogen Testing of sweetpotato training, April 2015. For Jean Bobby

9 Conclusions and recommendations

9.1 Conclusions

Sweetpotato plays a significant role in Papua New Guinean livelihoods. It is grown year round and depending on the location may occupy 55–90% of the arable land. In 2000 it was estimated that 81% of the rural population of Papua New Guinea (PNG) (then 4.3 million) grew sweetpotato (Omot 2012). Since the 1980s, in addition to being a rural subsistence food, it has increasingly been grown as a domestic market cash crop, catering to the escalating demand of expanding urban centres. From the perspectives of national food security and farm sustainability, it is important that the effects of crop pests and diseases are minimised. Viruses have been recognised as the diseases of most concern to the crop by researchers, while sweetpotato weevils have been identified as the major pest problem by both researchers and farmers.

The Australia sweetpotato industry is one of constant growth, with sales increasing by 20% per annum since the 1980s, due in part to its perceived health benefits—having high levels of antioxidants, vitamins, important dietary fibres and a low glycaemic index (Wolfenden 2014). Although a growth industry, retail markets dictate that roots must be of high quality, with minimal defects such as deformity, cracks and insect damage. To achieve maximum yields, the industry has identified viruses as the major disease problem and sweetpotato weevil (*Cylas formicarius*) (SPW) as the major insect pest affecting sweetpotato quality.

PC/2011/053 has identified that while viruses play an important role in causing sweetpotato yield decline, the interaction of plant and virus is not straightforward. The potyviruses *Sweetpotato feathery mottle virus* (SPFMV) and *Sweetpotato virus G* (SPVG) have been shown to readily infect sweetpotato in PNG, possibly with SPFMV being the more readily transmissible, as has been found in the USA. Co-infections of these viruses were also shown to occur.

Interestingly, the effect of these virus infections on yield decline indicates that PNG varieties may have some level of tolerance to viruses. This supports the suggestions of Okpul *et al.* (2011), who used some PNG varieties in his trials in Australia. However, there is still much to do to confirm this and to also discover the effects of co-infections in yield decline in PNG varieties.

PNG has been operating a seed scheme for potato (*Solanum tuberosum*) for a number of years and has accumulated considerable experience. It successfully operates where seed replenishment is required after four generations of field planting. The current commercial PNG sweetpotato varieties appear to show a similar yield decline, according to anecdotal evidence supplied by lead farmers who have cooperated with the project.

Therefore, the introduction of a pathogen-tested (PT) scheme for sweetpotato would have considerable advantages. It would extend the life of the commercial varieties, as farmers could replace them with the same PT variety as yield decline occurs. This would enable farmers to consistently produce the quality and quantity demanded by fresh markets. The availability of standard sweetpotato varieties with consistent root composition and quality would also allow for the development of processing industries. Given that farmers are used to obtaining fresh market prices for their sweetpotato, industries that have a higher margin value might be successful.

Sweetpotato production in Australia is a competitive business, requiring farmers to maximise yield of quality, marketable roots. This project has enabled the sweetpotato industry to improve its virus diagnostic capability. There is now a test for the presence of *Sweetpotato leaf curl virus* (SPLCV). This is a concerning virus, so providers of ‘seed’ need to ensure growers that their propagating material is free from it. This virus synergistically reacts with SPFMV (a commonly found virus), increasing the rate of yield decline. The fact that, to date, much of the industry does not appear to have been affected by this virus, or co-infections related to it, highlights the value of industry having a readily available supply of PT planting material to allow regular replacement of vines. The diagnostics used to find SPLCV are now being utilised to look for the presence of other sweetpotato viruses and phytoplasmas.

It has been important to ascertain that West Indian sweetpotato weevil (*Euscepes batatae*) (WISW) has spread to highlands, lowlands and island regions. Previously, ideas of mass pheromone trapping had been suggested as a main method of weevil control. As there is no pheromone for WISW lures cannot be used to control this weevil, although they may have a role to play with the control of SPW. However, on its own it will not be effective and an integrated pest management (IPM) strategy is called for. This is why the project has suggested area wide management (AWM) is the most promising approach for dealing with both weevils simultaneously.

A primary aspect of AWM is the restriction of breeding sites by removal of plant residues (unmarketable roots and old vines) from gardens as they are harvested. Once they understood the lifecycle of sweetpotato weevils, the co-operator farmers involved in this project grasped this concept well. PT planting material will also play an important role as vines, if sourced from screenhouses, should be free of weevil. The PT planting material will also mature faster than non-PT, enabling earlier harvests. In the commercial situation implementing a single harvest strategy will also restrict food sources for weevils. Further, the project identified that, with the exception of the damage caused by the larvae, farmer knowledge of sweetpotato weevils and their lifecycles is near nil, so an active extension program must be developed for farmers to fully understand the how's and why's for implementing an AWM program.

During the project, discussions were held as to the viability of establishing a PT scheme at a high altitude location such as Highlands Regional Centre (HRC), Tambul (2300 m above sea level). This area has a reduced risk of virus infections due to lower populations of virus vectors. SPW is not present. Surveys found WISW in gardens on the borders of the centre, but not in any of the sweetpotato crops or residues in the Centre's trial areas. A PT scheme based here will require a management strategy to ensure WISW does not enter the proposed production areas.

As cities and towns continue to grow in PNG there will be increased demand for sweetpotato, the staple most people have grown up with. There may also be demand for new sweetpotato products, e.g. sweetpotato fries, wedges and roasting portions. This demand needs to be met by developing sustainable production systems that maximise the quality and yield of the crop, a similar situation faced by Australian producers. This project has produced a better understanding of the major pests and diseases (viruses and sweetpotato weevils), and the lessons learned can be used in attaining these goals.

9.2 Recommendations

9.2.1 Viruses

1. Improve PNG's ability to diagnose sweetpotato viruses using PCR and other virus diagnostic technologies, such as loop-mediated isothermal amplification (LAMP).
2. Virus reinfection and yield decline studies have proven difficult to conduct at research stations. However, there is still a need to do these studies. It is recommended that several farm sites should be used as single replicates. Additional farm sites in different environments may provide added information on altitudinal effects. To be successful these trials should be done in consultation with farmers to ensure ownership. They need to be well resourced to allow officers adequate travel and time for extension/consultation, as well as to collect data.

3. Trial work has shown an advantage in using PT planting material. The co-operator farmers involved in this and previous projects are convinced of its value. It is recommended that a PT scheme should be established. A pilot scheme should be introduced using experience gained from the PT based seed potato (*Solanum tuberosum*) program. The pilot scheme should be developed through National Agricultural Research Institute (NARI) and Fresh Produce Development Agency (FPDA), working with a limited number of communities in those highland localities where training has been given to extension staff and Village Extension Worker (VEWs).
4. It is suspected that there may be more viruses affecting the Australian industry than have currently been reported. There is a need to continue surveying both sweetpotatoes and other host plants for these viruses. Similarly, the issues of virus co-infections need to be further investigated to identify which ones are occurring and the effect they have on production.
5. qPCR has enabled the Australian sweetpotato industry to find a virus of concern. The use of this technology needs to be further expanded to cover a wider range of viruses. Other technologies such as LAMP are being developed by International Potato Center (CIP) and should also be investigated as a tool for the Australian industry.
6. The two sweetpotato virus diagnostic workshops have led to major improvement in communication between Australian, Papua New Guinean, Fijian and CIP researchers. They have also led to improved standardisation of virus diagnostic protocols. There is a need to continue these workshops, preferably on a biennial basis.

9.2.2 Weevils and area wide management (AWM)

7. PNG farmers' knowledge of sweetpotato weevils is poor. It is recommended that an extension program is carried out to explain what sweetpotato weevils are and their biology and ecology.
8. In conjunction with sweetpotato weevil extension, a program demonstrating weevil control using AWM should be developed. Preferably the focus areas chosen would be those where PT planting material is being distributed. It is further recommended that as part of this strategy new sweetpotato growing practices are trialled with farmers; these would include practices such as the use of seedbeds for producing planting cuttings, watering after planting if required, and single harvesting.
9. Coffee ring borer (CRB) (*Meroleptus cf. cinctus*) was found to be infesting sweetpotatoes in Eastern Highlands Province (EHP). While there are mentions of this pest attacking plants other than coffee, there is almost no published information on this insect. It is recommended that studies on CRB are justified—at least surveys to see if there is an association of the pest with coffee plantings and sweetpotato gardens.

10 References

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10.2 List of publications produced by project

- *Review of sweetpotato PT in Papua New Guinea*—a review of the PT trials both on-station and on-farm that have been conducted in PNG
- *Sweetpotato weevils in Papua New Guinea and Australia*—a literature review covering the identification, ecology, life and breeding cycles, distribution and monitoring of both *Cylas formicarius* and *Euscepes batatae*. Distributed on the KauKauNet network
- Poster 'ACIAR PC/2011/053: Identifying appropriate strategies for reducing virus and weevil losses in sweetpotato production systems in Papua New Guinea and Australia' was produced for display at various shows and field days in PNG
- Article *Sweetpotato virus diagnostic training held at SPC* produced for SPC, 11 September 2013
- Kaukau Fact Sheet 6: Sweetpotato and West Indian kaukau weevils
- Kaukau Fact Sheet 7: Wireworms in kaukau
- Kaukau Fact Sheet 8: Growing better kaukau planting material
- Checklist for conducting sweetpotato trials
- Poster 'Biology of sweetpotato weevils'
- Poster 'Proper management tactics'

- Training brochures 'Identification of the two sweetpotato weevils (Cylas and Euscepes) to differentiate two weevils from larval to pupa stages'

11 Appendixes

11.1 Appendix 1. List of acronyms

Abbreviation	Description
ACIAR	Australian Centre for International Agricultural Research
AROB	Autonomous Region of Bougainville
asl	above sea level
ASPG	Australian Sweetpotato Growers Inc.
AVRDC	Asian Vegetable Research and Development Centre
AWM	area wide management
CePaCT	Centre for Pacific Crops and Trees
CIC	Coffee Industry Corporation
CIP	International Potato Center
CP	Central Province
CRB	coffee ring borer (*Meroleptus cf. cinctus*)
DAF	Department of Agriculture and Fisheries, Queensland
DAL	Department of Agriculture and Livestock, PNG
EHP	Eastern Highlands Province
FPDA	Fresh Produce Development Agency
GP	Gulf Province
GRF	Gatton Research Facility, Queensland
HP	Western Highlands Province
HRC	Highlands Regional Centre
IPM	integrated pest management
IVMV	*Ipomoea vein mosaic virus*
JP	Jiwaka
LAMP	loop-mediated isothermal amplification
NAQIA	National Agriculture Quarantine and Inspection Authority
NAQS	Northern Australia Quarantine Strategy
NARI	National Agricultural Research Institute, PNG
NCM-ELISA	nitrocellulose membrane – enzyme-linked immunosorbent assay
NGO	non-government organisation
PCR	polymerase chain reaction
PMV	Public Motor Vehicle
PNG	Papua New Guinea
PT	pathogen-tested
qPCR	real-time polymerase chain reaction
SHP	Southern Highlands Province
SPC	Secretariat of the Pacific Community
SPCFV	*Sweetpotato chlorotic fleck virus*
SPCSV	*Sweetpotato chlorotic stunt virus*
SPFMV	*Sweetpotato feathery mottle virus*
SPLCV	*Sweetpotato leaf curl virus*
SPMSV	*Sweetpotato mild speckling virus*
SPVD	*Sweetpotato virus disease*

Abbreviation	Description
SPVG	*Sweetpotato virus G*
SPW	sweetpotato weevil (*Cylas formicarius*)
VEW	Village Extension Worker
WHP	Western Highlands Province
WISW	West Indian sweetpotato weevil (*Euscepes batatae*)
WP	Western Province