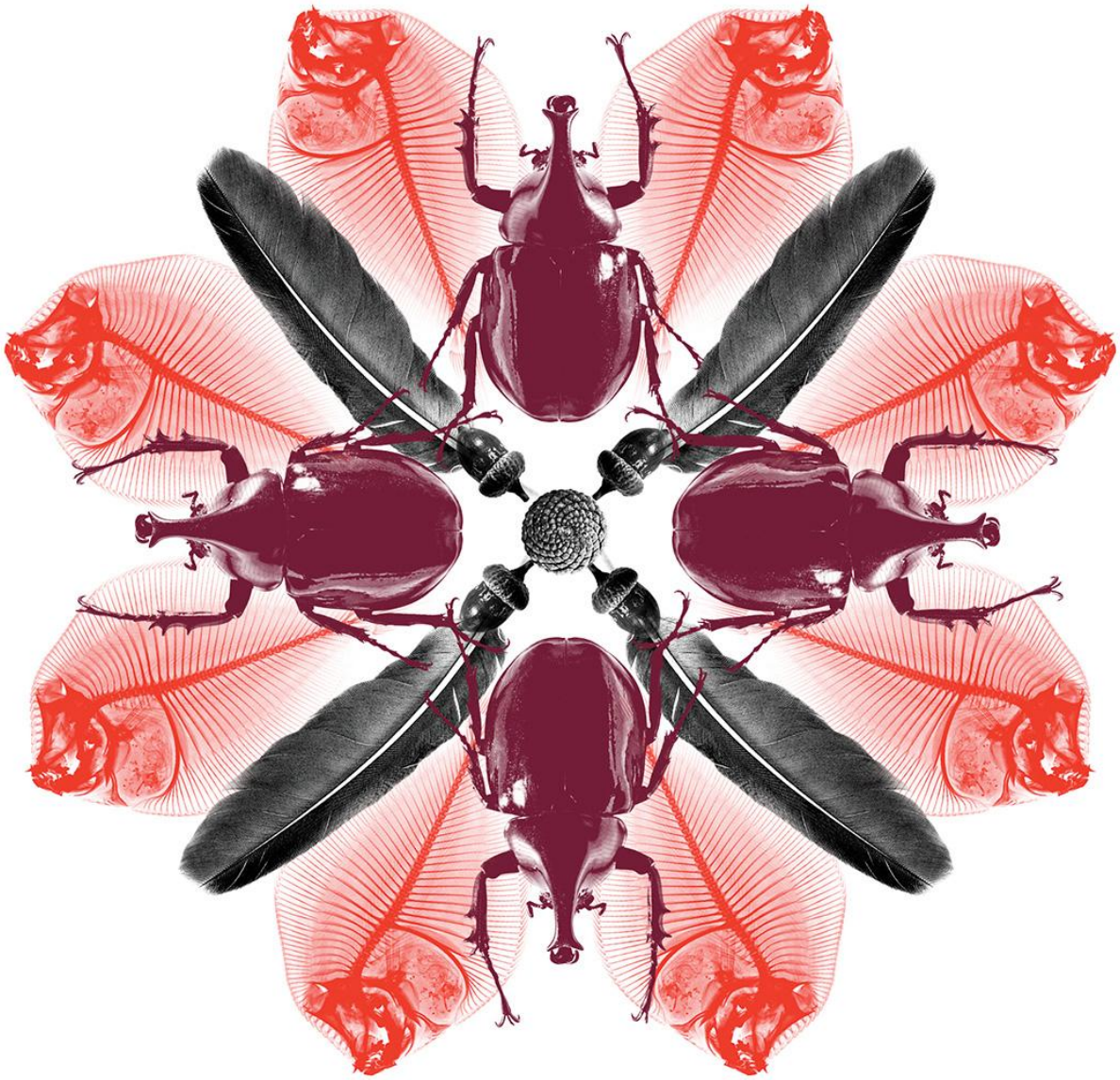
Australian Government
Department of Agriculture

Review of import conditions for fresh ginger from Fiji

Draft report

June 2015



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Stakeholder submissions on draft reports

This draft report has been issued to give all interested parties an opportunity to comment on relevant technical biosecurity issues, with supporting rationale. A final report will then be produced taking into consideration any comments received.

Submissions should be sent to the Australian Department of Agriculture following the conditions specified within the related Biosecurity Advice, which is available at: agriculture.gov.au/ba/memos

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Executive summary

A review of the import conditions for fresh ginger from Fiji was announced on November 17, 2014. This review was undertaken to meet a commitment in the final import risk analysis for fresh ginger from Fiji, which was released in January 2013. Its terms of reference include evaluating the efficacy of measures applied to manage the biosecurity risks associated with fresh ginger from Fiji, and making recommendations on actions needed to confirm the quarantine status of the burrowing nematode, *Radopholus similis*, and the efficacy of any phytosanitary measures for managing it and pests of quarantine concern. The review is supported by an extensive literature review and analysis of the science relevant to the quarantine status of *Radopholus similis*.

Inspection outcomes of the five consignments of ginger imported in the first year of trade, including laboratory analyses of samples from these imports, were also assessed and are presented.

Outcomes of ginger imports in the first season

A total of five consignments of fresh ginger were exported from Fiji to Australia in late 2014 and early 2015. These are the first imports under the permits issued, which apply the measures set by the Import Risk Analysis for fresh ginger from Fiji. All consignments were accompanied by the appropriate phytosanitary certification by Fiji biosecurity authorities and were inspected by the Department of Agriculture when they arrived in Australia. No live quarantine pests were detected during the department's inspections, and all five consignments were released from quarantine. Some non-quarantine pests were detected with no remedial action required, and a number of dead insects were also noted.

Yam scale (*Aspidiella hartii*) was detected on four consignments of imported ginger during the first season of trade and prompted a review of phytosanitary measures for this quarantine pest. The current requirement is for imported ginger to be free of yam scale based on a standard 600 unit inspection. The finding of yam scale during import inspections indicates that this requirement has not been met. On-arrival inspections and independent testing confirmed that all yam scales detected were dead. This is an expected consequence of fumigation with methyl bromide and the department therefore recommends a mandatory methyl bromide fumigation treatment be introduced for yam scale.

Some non-quarantine pests were detected with no remedial action required.

Quarantine status of *Radopholus similis*

The department undertook a comprehensive review of *Radopholus similis* covering:

- the scientific literature
- the historic and current situation of *Radopholus similis* on ginger in both Fiji and Australia, and
- interceptions on imports of Fiji ginger into Australia over the first (2014–15) season

In undertaking the review the department consulted with technical experts nominated by the Australian ginger industry, Queensland Department of Agriculture and Fisheries (QDAF) and Biosecurity Authority of Fiji (BAF). The department also visited ginger production areas in Queensland and Fiji, held discussions with technical experts during these visits and actively sought additional relevant information.

The scientific literature

The department and technical experts representing the Australian ginger industry, QDAF and BAF agreed that the *Radopholus similis* pathogenicity experiments conducted in Fiji during 2009 (Turaganivalu *et al.* 2009; 2013) and Australia during 2012 (Cobon *et al.* 2012) were not directly comparable and do not provide scientific proof of a significant difference between Fijian and Australian *Radopholus similis* isolates on ginger.

The review found no clear supporting scientific evidence in the wider biological literature for the existence of a strain of *Radopholus similis* in Fiji with significantly different pathogenicity on ginger compared to *Radopholus similis* already present in Australia. There is no consistent scientific evidence in the literature for biological factors influencing differences in pathogenicity and host preference in *Radopholus similis*.

The historic and current situation of *Radopholus similis* on ginger in both Fiji and Australia

In 2007, a survey of 22 farms across nine Fijian ginger growing regions recorded significant damage caused by *Radopholus similis* on some farms in the Veikoba district. *Radopholus similis* was also recorded in low numbers at Muanaweni.

However, there is currently no evidence that *Radopholus similis* is causing damage in ginger fields in Fiji. Surveys of soil and ginger conducted by the Fijian Ministry of Agriculture's Research Division across a range of ginger farms in seven localities between June and September 2014, including fields that were infested with *Radopholus similis* in 2007, detected no *Radopholus similis* (although other nematode species were detected). Further sampling of volunteer ginger (regrowth from previous crop) and crowsfoot (a weedy host of *Radopholus similis*) in February 2015 also detected no *Radopholus similis*.

Fiji has indicated that ginger production practices have been modified to prevent and manage infestation with *Radopholus similis*. Ginger production in Fiji currently involves crop rotation with plants that are not hosts for *Radopholus similis* with some growers also including an additional six month fallow period. Growers are also encouraged to plant in new areas not previously used for ginger production. Growers receive extensive training on seed treatment and preparation and equipment is provided on a loan scheme for hot water treatment of seed.

Draft conclusion

There is insufficient scientific evidence to support the claim that Fiji has a strain of *Radopholus similis* with significantly different pathogenicity on ginger compared to *Radopholus similis* already present in Australia.

The department and technical experts representing the Australian ginger industry, QDAF and Fiji agree that the only way to scientifically prove such a difference would be to do an experiment comparing Fijian and Australian *Radopholus similis* isolates side-by-side in an

appropriately controlled trial using a methodology agreed by all parties. The department is prepared to reconsider the quarantine status of *Radopholus similis* if a significant biological difference can be scientifically proven in this way.

Initial discussions with the Fijian authorities indicate that no *Radopholus similis* cultures (alive or dead) are being held in Fiji. It may be difficult to source new specimens from the field considering its current reported low prevalence.

The ongoing application of phytosanitary measures against *Radopholus similis* cannot be justified since it does not meet internationally recognised criteria for a quarantine pest. It follows that questions of treatment efficacy in relation to *Radopholus similis* are also no longer relevant.

The department is prepared to review import conditions if additional relevant information becomes available.

1 Introduction

Why is the department undertaking a review of import conditions?

The Department of Agriculture may review import conditions at any time to ensure that import policy is appropriate to manage the biosecurity risks while still meeting Australia's international obligations. The department made a commitment in the final IRA report to review the import policy after one year of trade. The focus of the review is on:

- the quarantine status of the burrowing nematode, *Radopholus similis*, which was unresolved at the time the import policy was finalised in 2013; and
- the effectiveness of phytosanitary measures, following public concern about potential pests in imported ginger.

The final import risk analysis (IRA) report for fresh ginger from Fiji was published on 22 January 2013. The IRA report identified a number of pests of quarantine concern to Australia including a putative intraspecific ginger variant of *Radopholus similis*. Previously, *Radopholus similis* had not been regulated as a quarantine pest, as it is already present in Australia.

During the IRA process, the Australian Ginger Industry Association (AGIA), the Queensland Department of Agriculture and Fisheries (QDAF) and other stakeholders claimed that the *Radopholus similis* in Fiji was significantly more pathogenic than the one in Australia and hence should be regulated as a quarantine pest. Considering the veracity of these claims was beyond the scope of the IRA report at the time. Nevertheless, the department took a conservative approach and provisionally accepted *Radopholus similis* as a quarantine pest in the final IRA report, pending provision of additional evidence and further assessment. This review provides the opportunity to re-examine *Radopholus similis* and assess any new information that has become available since the IRA report was published.

The review also allows the department to consider whether the import conditions are effectively managing biosecurity risk, and if not, recommend changes to manage the risks. Following the commencement of ginger imports from Fiji in September 2014, concerns were raised about the presence of live root knot nematodes (*Meloidogyne* spp.) found in a consignment of fresh ginger. These nematodes were included in the IRA but were not considered to be quarantine pests because they are established in Australia.

Terms of reference

The terms of reference for the review are to:

- Evaluate the efficacy of the measures applied to manage the biosecurity risks associated with fresh ginger from Fiji by:
  - analysing and evaluating pest interceptions from on-arrival inspections, including evaluating the compliance of on-arrival fumigation
  - evaluating information from audits in Fiji

  - gathering, recording and evaluating any information on additional processes in Fiji to ensure compliance with the import requirements, and
  - evaluating any other relevant additional scientific information that is available.
- Consider and make recommendations on further actions to confirm the quarantine status of *Radopholus similis*, including additional scientific information relating to this including on the efficacy of methyl bromide as a phytosanitary measure.

The review is not revisiting the pest risk assessments done previously in the IRA. However, the review is examining the biosecurity risks identified during the first season of trade, and considering the appropriateness of the import conditions and phytosanitary measures.

Submissions to the review

The Biosecurity Advice containing the review terms of reference, published on the department's website on 17 November 2014, invited technical submissions for consideration by the department. Submissions were received from AGIA, QDAF and a joint submission was received from the Biosecurity Authority of Fiji (BAF) and Fiji Ministry of Agriculture (MoA). These submissions are available on the department's website.

The major issues raised by stakeholders related to *Radopholus similis*, its status as a quarantine pest, and the efficacy of phytosanitary treatments against it. These issues are addressed in this report.

A number of other issues were raised that are outside of the scope of the review. Some have been addressed by the review findings and proposed changes to import conditions. Others are outside the scope of the regulatory framework of the *Quarantine Act 1908*.

Good agricultural practice

The review has clearly demonstrated the importance and value of crop rotation and seed quality and hygiene to manage ginger pests in Fiji and Australia. This has underlined the critical importance of on-farm biosecurity to safeguard industries from the impacts of pests – both exotic and established – on yield, quality, production costs, market access and long term sustainability.

Diversion of fresh ginger for planting purposes

The diversion of imported Fiji ginger for planting by Australian ginger growers was raised in the AGIA submission. It was also raised as an issue in consultation during the IRA process.

The IRA took into account the diversion of use and this review further recommends measures to prevent the introduction of yam scale on imported ginger from Fiji. There has been no *Radopholus similis* detected in the ginger from Fiji.

However, the Australian industry remains vulnerable to the impacts of root diseases such as *Pythium* and *Fusarium* spp., which can be introduced to crops through planting material. This was discussed with the review team during its visit to production areas in Queensland. Integral to protecting the industry from established diseases are good agricultural practices including crop rotation, use of clean seed and field hygiene. Other Australia plant industries using vegetative propagation, such as potatoes and strawberries, have developed clean seed schemes

to provide their industry with a secure source of quality seed. This reduces the high risk practice of using planting material sourced from the market floor. The Australian ginger industry is likely to similarly benefit from a high health seed scheme, which would reduce the likelihood that any ginger rhizomes purchased from markets – whether of domestic or overseas origin – would be planted.

Consultation

Stakeholders were invited to make submissions presenting relevant technical information for consideration when the commencement of the review was announced in November 2014. Stakeholders were also invited to nominate relevant scientific experts to assist during the review.

A panel of technical experts was assembled from the nominated experts willing to participate in the review. The panel convened for a teleconference on 20 January 2015 to discuss the review process, past and current research on *Radopholus similis*, and potential experimental design for future research. The minutes from this teleconference are presented in Appendix 4.

Department officials subsequently met with the AGIA and visited some ginger farms on the Queensland Sunshine Coast on 2 March 2015 to gain a better understanding of Australian ginger production practices, farm biosecurity and pest management. This was followed by a technical meeting with QDAF and AGIA in Brisbane on 3 March to discuss *Radopholus similis* pathogenicity and observe a pathogenicity experiment being conducted at the QDAF facility. A number of issues that could be raised and investigated with the Fiji authorities were identified. A summary of the Brisbane meeting and outcomes is presented in Appendix 4.

Department officials travelled to Suva, Fiji to meet with BAF and MoA and visit the main ginger production areas on Viti Levu from 10 to 12 March 2015. MoA provided an update on the activities of the extension officers, the registration process for growers and prospects for the 2015 export season. A number of ginger farms were visited to observe crop health, production practices and pest management. With the exception of the seed farm in Rakiraki, all these ginger farms are registered for export. Three packhouse facilities that are registered for export were also visited, as well as the Koronivia Research Station at Nausori, where nematode testing and research is undertaken. A more detailed summary of the Fiji visit is presented in Appendix 5.

2 Analysis of the importation of ginger from Fiji

Fresh ginger imports from Fiji in 2014–15

The importation of fresh ginger from Fiji commenced with the first consignment arriving in Australia on 15 September 2014 and concluded with clearance of the last consignment on 9 January 2015. These are the first imports under the permits issued, which apply the measures set by the Import Risk Analysis for fresh ginger from Fiji.

The 2014–15 Fijian ginger season comprised five air–freight consignments. Three consignments were imported into Sydney, with the other two arriving in Melbourne. All consignments were inspected by the Department of Agriculture when they arrived in Australia. No live quarantine pests were detected during the department's inspections, and all five consignments were released from quarantine. Some non-quarantine pests were detected with no remedial action required, and a number of dead insects were also noted.

All imported ginger was subject to mandatory fumigation with methyl bromide for the target pest, *Radopholus similis*. The import requirements provide that fumigation treatment can be applied in Fiji (offshore) or when the ginger arrives in Australia (onshore). Both options were used during the 2014–15 season, with four of the five consignments fumigated on arrival in Australia.

Further information on import policy and Australia's biosecurity legislation is presented in Appendix 1.

Permits

The *Quarantine Proclamation 1998*, section 64 (2) prescribes that the importation of all fresh fruit and vegetables (including fresh ginger) is prohibited unless a Director of Quarantine has granted the person a permit to import it into Australia. Permission is provided in the form of an import permit issued by the department.

The department assessed and granted seven import permits for the 2014–15 season. The first import permit was assessed by the department and granted on 14 August 2014. All import permits are valid for 12 months from the date of issue. No import permits have been suspended, revoked, or varied. One permit application was withdrawn. Until the review is finalised, Fiji is able to continue to trade under existing import conditions.

Mitigation measures

Conditions for importation of fresh ginger from Fiji are presented in Appendix 1. The measures take a whole of pathway perspective, recognising that biosecurity risk is managed in many steps along the import pathway.

The import of fresh ginger from Fiji is contingent upon meeting the requirements specified on the import permit.

Fijian ginger is subject to mandatory fumigation with methyl bromide, either in Fiji or in Australia. Each export consignment destined for Australia is also prepared following good

commercial practice including cleaning, quality inspection, packing and storage. The final pre-export step is for each consignment to be inspected by the Biosecurity Authority of Fiji and certified as meeting Australia's import requirements.

The department requires each consignment to be inspected at a quarantine approved premises on arrival, to verify that the ginger is clean and free from any biosecurity risk material, including any quarantine pests, and that it meets Australia's import requirements.

To ensure that permit conditions are met and exported ginger meets commercial requirements, a range of additional actions have been taken in Fiji with the assistance of the Fiji Government. These were observed in Fiji during pre-trade audits and the field visit by department officers during this review.

At present, fresh ginger from Fiji is subject to strict controls by the Ministry of Agriculture in Fiji to both optimise crop production and quality, and reduce the risks of pests and diseases in export crops. These include:

- registering export farms, packing facilities and exporters,
- sourcing of high quality clean seed rhizomes,
- treatment of seed rhizomes prior to planting,
- crop monitoring and soil testing to detect the presence of pests like *Radopholus similis*,
- crop rotation with alternative crops such as taro or cassava, to reduce risks of *Radopholus similis* and other soil borne pests, and
- fallowing of land prior to planting with export crops, or using virgin land.

Inspection requirements

All imported Fijian ginger consignments were inspected by the department in accordance with standard inspection practices for the presence of soil, live quarantinable insects and diseases, and any other contaminants of biosecurity concern. Consignments were also inspected to confirm documentation requirements had been met and that the Phytosanitary certificate was authentic and appropriate.

Additionally, the department undertook to confirm the outcome of its inspection through independent testing of representative samples from each consignment. One of those samples was further split into four sub-samples for nematode extraction, three of which were independently microscopically examined in laboratory conditions by three separate testing organisations.

Summary of imports

Details of the five consignments of ginger imported from Fiji during the 2014–15 season are presented in Table 1.

All ginger was certified as being sourced from registered farms and prepared for export in approved packing facilities. All five consignments were appropriately certified and accompanied by Phytosanitary certificates issued by BAF. The correct additional declarations were applied. No documentation concerns were noted.

All consignments were inspected by Department of Agriculture inspectors when the consignments arrived in Australia. Inspections were performed at quarantine approved premises or department offices at the first port of arrival, and performed in accordance with the department's instructions and guidelines for inspecting fresh Fijian ginger.

All consignments were subject to methyl bromide fumigation (one consignment was treated in Fiji prior to export, and four were fumigated on arrival in Australia).

There were no detections of *Radopholus similis* (live or dead) in any of the consignments. This was confirmed by additional independent testing.

Aspidiella hartii (yam scale) was detected in four of the consignments but all specimens found were dead. This was confirmed by independent testing.

Three consignments contained live nematodes resembling *Meloidogyne incognita* (root knot nematode). *Meloidogyne incognita* is not of quarantine concern as it is established in Australia, and therefore no further action was taken. One consignment contained live non-parasitic *Rhabditis* sp. and *Panagrolaimus* sp. nematodes, which are not of quarantine concern. One consignment contained several plant-parasitic *Helicotylenchus* spp. (spiral nematodes) but these were all dead, as well as three live species of non plant parasitic nematodes.

No soil, plant trash, or growing shoots was found in any of the consignments at inspection.

All five consignments were released from quarantine following fumigation and department inspection.

Samples from all consignments were subjected to independent examination to check for presence of quarantine pests. The results were consistent with those found by the department.

Analysis of phytosanitary measures and operational procedures

Efficacy of phytosanitary measures

No live quarantine pests were detected in any of the imported ginger consignments examined by Australian authorities at the border. All consignments were subject to a 600 unit (600 individual rhizome pieces) inspection on-arrival prior to release from quarantine. Optical enhancement is used in the inspection procedure to examine for microscopic organisms that may be present.

Additionally, the department collected some rhizomes in each consignment for further testing for the presence of nematodes. Samples were sent to independent laboratories in South Australia (University of Adelaide), Victoria (Crop Health Services, Department of Environment and Primary Industries) and Canberra (CSIRO Black Mountain) to extract and identify any nematodes present. No quarantine pest nematodes, alive or dead, were detected in the imported ginger samples. Some other nematodes were extracted from the samples, including some that were still alive.

Table 1 Ginger consignments imported from Fiji 2014–15

Entry no.	Volume (kg)	Region	Date released	Fumigation	Incidents	Comments
ACH7GG3KN	494.12	NSW	15/09/2014	Fiji	*Penicillium* sp. *Fusarium* sp. *Rhabditis* sp. *Panagrolaimus* sp.	No live quarantine pests were found during inspection. Consignment released from quarantine. A single box of ginger was obtained by the department and split into four subsets for testing. Three subsets were sent for independent analysis to CSIRO Black Mountain (Canberra), Crop Health Services (Melbourne) and the University of Adelaide. No pests of quarantine concern were detected in any subset.
ACH77MLNN	760	NSW	18/09/2014	Australia	*Aspidiella hartii* (dead) *Meloidogyne* sp. (live)	No live quarantine pests were found during inspection. Consignment released from quarantine. Several ginger rhizomes were subsequently forwarded to the department by QDAF for examination. Dead yam scale was found and some live nematodes (likely a root knot nematode, not of quarantine concern).
ACJJA7A43	1000	Victoria	23/10/2014	Australia	*Aspidiella hartii* (dead) *Meloidogyne incognita* (live)	No live quarantine pests were found during inspection. Consignment released from quarantine. Twelve samples (rhizomes) taken and secured under continuous custody by the department, Melbourne office. One sample was forwarded to Crop Health Services, Melbourne for analysis. Yam scale was detected and confirmed dead. Some live nematodes were detected but all confirmed as *Meloidogyne incognita*, which is not of quarantine concern.
ACJRG9CRY	2300	Victoria	20/11/2014	Australia	*Aspidiella hartii* (dead) *Meloidogyne incognita* (live)	No live quarantine pests were found during inspection. Consignment released from quarantine. Samples were taken and secured under continuous custody by the department, Melbourne office. One sample was forwarded to Crop Health Services, Melbourne for analysis. Yam scale was detected and confirmed dead. Some live nematodes were detected but all confirmed as *Meloidogyne incognita*, which is not of quarantine concern.
ACKAJX3KY	291	NSW	9/01/2015	Australia	*Aspidiella hartii* (dead) *Helicotylenchus* sp. (dead)	No live quarantine pests were found during inspection. Consignment released from quarantine. Six samples (rhizomes) taken and secured under continuous custody by the department, Melbourne office. One sample was forwarded to Crop Health Services, Melbourne for analysis. Yam scale and spiral nematodes were detected and confirmed dead. Some live nematodes were detected but all were confirmed as non plant parasitic and not of quarantine concern.

Efficacy against *Radopholus similis* (burrowing nematode)

No *Radopholus similis*, live or dead, have been found in any of the consignments inspected at the border, or in any of the samples sent for further nematode testing. No symptoms indicating the presence of *Radopholus similis* have been reported in the imported consignments. Recent field surveys in Fiji have not found *Radopholus similis* in any of the export ginger production areas (Ministry of Agriculture 2015), which suggests that the nematodes are unlikely to be in the ginger when it is harvested.

Efficacy against *Aspidiella hartii* (yam scale)

Australia rarely requires mandatory phytosanitary measures to mitigate armoured scales in horticultural imports, as these pests are typically assessed to be below Australia's appropriate level of protection (ALOP). However, the final IRA report rated the risk posed by yam scale to be low, which is above Australia's ALOP, and therefore measures were required to manage the risk to an appropriate level. The IRA recommended freedom from *Aspidiella hartii* (yam scale) in exported consignments, which is verified by phytosanitary inspection and certification. This was considered to be an appropriate measure for *Aspidiella hartii* on ginger, as phytosanitary inspection is also commonly required for similar pests on horticultural imports such as mealybugs and soft scales.

The presence of dead *Aspidiella hartii* in some of the consignments is concerning and indicates that phytosanitary inspection alone is failing to detect all scales that may be present. Even though all the scales found have been dead, this is most likely the result of the fumigation treatment currently in place for *Radopholus similis* as there are no other phytosanitary measures, or any pre-export handling processes, that would account for the mortality of all the scales present.

Four of the imported consignments were fumigated on arrival in Australia, after being inspected and certified as free of *Aspidiella hartii* by the authorities in Fiji prior to export. In three of those consignments, dead scales were subsequently found on the ginger during quarantine inspection in Australia after it was fumigated. In the other consignment, dead scales were only found when a ginger sample was returned to the department by QDAF, after previously clearing quarantine inspection.

Significance of non-quarantine organisms in consignments

There are few pests associated with ginger in Fiji that are of quarantine concern to Australia. Most ginger pests in Fiji are already present in Australia. Among these pests are root knot nematodes (*Meloidogyne incognita*, *Meloidogyne javanica* and *Meloidogyne arenaria*), armoured scales (*Aspidiotus destructor*), mealybugs (*Dysmicoccus brevipes*) and the microorganisms responsible for Pythium rot (*Pythium myriotylum*), and Fusarium yellows (*Fusarium oxysporum* f. sp. *zingiberi*).

In addition to these ginger pests, there are other contaminant organisms and cosmopolitan storage pests associated with international movement of horticultural commodities, which may be detected from time to time. If such organisms are detected on ginger during inspection, they are identified and managed through operational procedures.

Review of pre-export audits

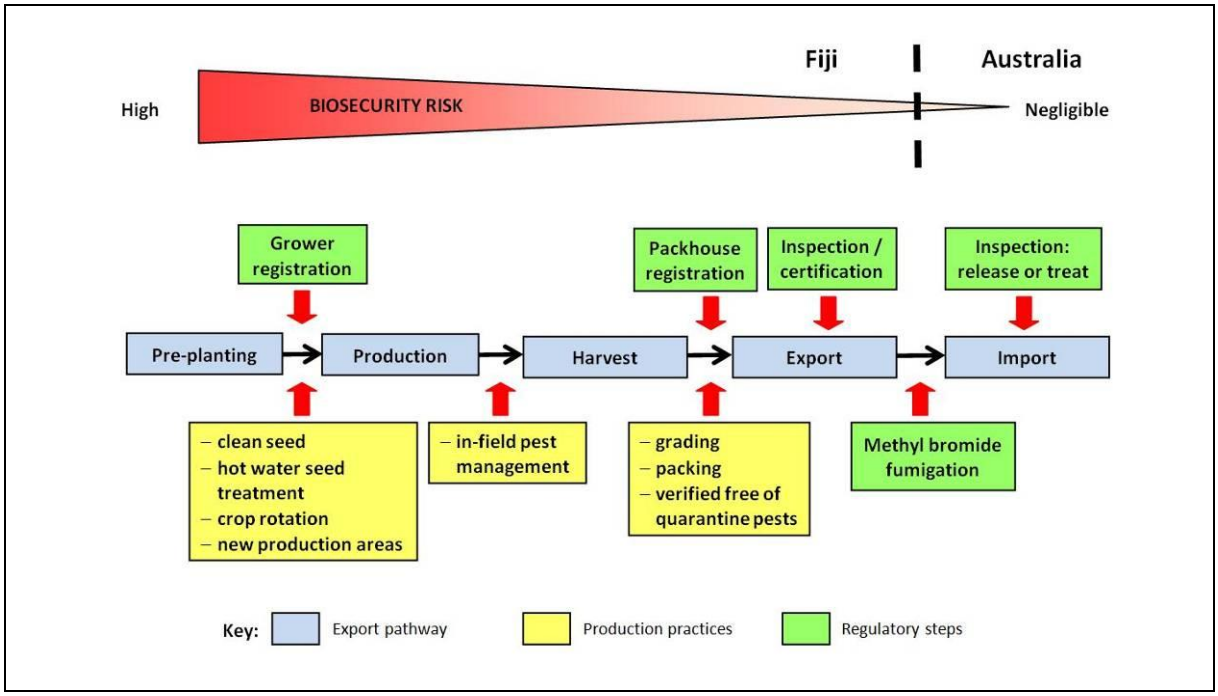
The department has completed two audits of the operational system for exports of ginger in Fiji. The first was conducted between 15 and 17 October 2013. The second was undertaken on 3 and 4 September 2014, immediately prior to the first ginger exports to Australia.

The latter audit covered ginger farms, two packing facilities processing product for export to Australia, a treatment provider, freight forwarders and the regulatory activities of BAF and MoA. The audit detected an administrative non-conformance in supporting documentation and record keeping. Corrective action was undertaken immediately by BAF.

Managing biosecurity risk along the importation pathway

Biosecurity risk is managed in many steps along the import pathway. This is represented schematically in Figure 1. As described previously, a number of practices undertaken prior to planting, during crop production and post-harvest, contribute to mitigating pest and disease risks. The pre-export phytosanitary inspection and the fumigation treatment all reduce the risks even further. The on-arrival verification inspection is the final step prior to release of the consignment, providing assurance of the import pathway.

Figure 1 Fiji ginger production and risk management system



3 Import policy and regulation of *Radopholus similis*

Why is the department reviewing *Radopholus similis*?

Import policy in Australia has not historically been concerned with *Radopholus similis* nor treated it as a quarantine pest since it is already present in Australia and is not under official control within Australia. Its movement is not being regulated within Australia to prevent its spread. *Radopholus similis* was first identified in Australia nearly a century ago (Illingworth 1920), and it presently has a wide distribution in coastal parts of northern Australia.

In the final IRA report for fresh ginger from Fiji, the department provisionally recognised a putative intraspecific ginger variant of *Radopholus similis* as a quarantine pest. This was based on claims made by QDAF during consultation in 2012 that the pest in Fiji was significantly more pathogenic than the one present in Australia. At the time there was evidence that *Radopholus similis* was (or had been in the recent past) a significant pest of ginger in Fiji, while it has never been reported as a pest in Australia's ginger production areas, suggesting there were possibly biologically different variants.

The international scientific literature does not recognise the existence of a unique ginger variant of *Radopholus similis* in Fiji or anywhere else in the world, and specific research comparing *Radopholus similis* populations in Fiji and Australia is limited. The department took a conservative approach and provisionally accepted *Radopholus similis* as a quarantine pest in the final IRA report, pending provision of further evidence and further assessment, which was outside the scope of the IRA at the time.

Article 5.7 of the SPS Agreement states:

> In cases where relevant scientific evidence is insufficient, a Member may provisionally adopt sanitary or phytosanitary measures on the basis of the available pertinent information, including that from the relevant international organizations, as well as from sanitary or phytosanitary measures applied by other Members. In such circumstances, Members shall seek to obtain the additional information necessary for a more objective assessment of risk and review the sanitary or phytosanitary measure accordingly within a reasonable period of time.

As the department's decision resulted in additional phytosanitary measures that have an impact on trade, Australia is obliged under the SPS Agreement to justify its decision and present credible scientific evidence to substantiate its position. This review is aiming to resolve whether *Radopholus similis* meets the scientific criteria to be considered a quarantine pest for ginger from Fiji.

The assessment of *Radopholus similis* in the IRA

Radopholus similis was not recognised as a quarantine pest in the draft IRA report released for stakeholder comment in April 2012. Therefore the quarantine risks associated with its importation were not assessed at the time. However, QDAF subsequently provided information about a preliminary unpublished study it had undertaken, which indicated that there was a possibility that *Radopholus similis* in Fiji was exhibiting higher pathogenicity on ginger. On this

basis, the department provisionally accepted *Radopholus similis* as a quarantine pest in the final report.

The IRA for fresh ginger from Fiji assessed the putative intraspecific variant of *Radopholus similis*, and determined the unrestricted risk to be low, which is above Australia's appropriate level of protection. As a result, additional phytosanitary measures were required to reduce the risk to an acceptable level.

Radopholus similis in Fiji's ginger production

Although recognised as a pest of ginger production in Fiji, there are few reports to indicate how prevalent and widespread *Radopholus similis* has been in Fiji's ginger production historically. Damage to ginger caused by *Radopholus similis* was first noted in Fiji around 1970. It was estimated to be present in less than ten per cent of the ginger crop in 1975, but in some fields the infestation could be as high as fifty per cent, reducing yields by nearly forty per cent (Vilsoni *et al*. 1976). Another survey by Orton Williams (1980) found *Radopholus similis* was occasionally present in ginger.

A 2007 survey (Smith *et al*. 2012) found *Radopholus similis* was still a problem in some areas. *Radopholus similis* was considered to be a significant pest of ginger in Fiji at the time the department was considering commencing an IRA for fresh ginger from Fiji. *Radopholus similis* has not been detected in Fiji's commercial ginger crop since 2010 (U Turaganivalu 2015, pers. comm. 29 April).

Further discussion on the history of *Radopholus similis* in Fiji is presented in Appendix 2.

Why was *Radopholus similis* a problem in Fiji's ginger crop?

Problems with *Radopholus similis* in Fiji's ginger production have been largely attributed to the repeated introduction of the pest in infested planting material (Turaganivalu *et al*. 2013), suggesting that adopting better farming practices would manage or mitigate the problem.

The commercial ginger industry in Fiji underwent a period of decline in the 1990s due to greater competition for export markets from China and Brazil, and falling government assistance. Consequently there was neglect in maintaining farming practice standards, including the selection of healthy planting material, hot water treatment of seed, crop management practices and post-harvest handling (Gonemaituba 2008).

A number of practices that help manage pest and disease problems were not being undertaken at that time. A farmer survey indicated that only nine per cent of farmers treated their seed material using hot water vats during the 2006 season (Gonemaituba 2008). Where seed treatments were done, they were not always performed properly, increasing the likelihood of nematode pests being introduced into the crop. While many farmers were using a crop rotation program, poor weed control meant that pests could survive on weeds and volunteer plants from previous crops, or infested material was left to rot in the field rather than being removed and destroyed to prevent reinfestation.

The poor standards of crop management and seed treatment by some growers meant that nematode populations were able to grow to damaging levels, resulting in significant losses on some farms (Turaganivalu *et al*. 2013).

What has changed?

In recent years Fiji's Ministry of Agriculture has undertaken a number of activities to improve ginger production practices in anticipation of exporting to Australia. The Fiji Government has provided significant support for the implementation of the ginger export program, and reinvigorated its extension program.

Targeted training sessions have been provided to farmers intending to produce ginger for the export market, covering agronomical practices, pest and disease management and standard operating procedures for the export pathway. Assistance is provided to all registered farmers, and 560 growers in the Central Division had attended training sessions as of March 2015 (Ministry of Agriculture 2015). A Technical Bulletin (see Appendix 3) was developed to provide guidance to growers on the recommended package of production practices and procedures (Ministry of Agriculture 2013).

Current pest status of *Radopholus similis* in Fiji

Radopholus similis was last detected in Fiji's ginger crop in 2010, on a farm in Veikoba where the pest had previously been found. It was found on banana in Naitasiri in 2011 (U Turaganivalu 2015, pers. comm. 29 April).

Field observations by the MoA extension officers providing assistance to the ginger farmers, nematode surveys and analysis of ginger imported into Australia in the 2014 season all indicate that *Radopholus similis* is not prevalent in Fiji's export ginger production. *Radopholus similis* is not currently a problem in any of Fiji's commercial ginger growing districts. The pest has not been found in recent nematode field surveys, and growers have not reported disease symptoms of *Radopholus similis* infestation in their crops for some time. There is no suggestion that it has been eradicated, and it is likely that *Radopholus similis* is still present in some areas in low numbers, or surviving on other host plants.

Ginger nematode surveys

As part of the grower registration process, the MoA has undertaken soil testing to determine the nematode fauna present in fields where ginger is grown. No *Radopholus similis* was found in any of the fields tested in 2014 (Ministry of Agriculture 2015). A MoA summary report of this survey work is available on the department's website.

A total of 55 ginger farms were surveyed in seven localities in 2014, including Muanaweni (June), Navua (July), Waibau, Veikoba, Lomaivuna and Naboro (September). Additional surveys of volunteer ginger, crowsfoot, banana, taro and cassava were carried out in February 2015 on farms in Veikoba that were previously known to be infested with *Radopholus similis* in 2007.

Nematode sampling and identification was done by the MoA Research Division. Soil samples from 55 sites were collected from ginger farms, as well as other crops including banana, eggplant and cucumber. Samples from weeds (crowsfoot), and fallow fields, pasture and forest were also collected. Ginger rhizomes from Bureni, Naivurevure, Muanaweni and Navua were also tested.

Soil sampling involved taking soil (to a depth of 20 centimetres) from the rhizosphere of ten plants in each field, then combining subsamples into a single composite sample. Nematode

extraction involved spreading 200 millilitres of soil on an extraction tray for 48 hours and then filtering twice through a 38 micrometre sieve.

Extracting nematodes from the rhizome samples involved cutting into 70 gram pieces, placing in 200 millilitres of water and macerating in a blender for 10 seconds. The material was then placed on an extraction tray for 24 hours and sieved.

Nematodes were identified using morphological characters by the nematologist at the Koronivia Plant Pathology laboratory. Four genera of nematodes were commonly found in the surveys: *Rotylenchulus reniformis* (reinform nematode), *Helicotylenchus* spp. (spiral nematodes), *Criconema* spp. (ring nematodes) and *Meloidogyne* spp. (root knot nematodes). These same nematodes were also present in the soil samples collected from around banana and eggplant, and in the samples from fallow land. No *Radopholus similis* were extracted from any of the soil or rhizome samples. Only *Meloidogyne* spp. were extracted from the rhizome samples, from one field at Navua.

Rotylenchulus reniformis was found in the soil of 41 of the 55 fields surveyed, and was by far the most widely distributed nematode present. *Helicotylenchus* spp. were found in the soil from 23 fields, particularly in the Naboro district (13 of 16 fields tested). *Criconema* spp. were found in 14 fields, while *Meloidogyne* spp. were present in the soil in six fields in Waibau, Navua, Veikoba and Naboro.

Relative nematode population densities between species varied in the samples. *Rotylenchulus reniformis* was the most numerous species in 51 per cent of the samples, *Helicotylenchus* spp. the most common in 28 per cent of samples, *Criconema* spp. in 13 per cent and *Meloidogyne* in ten per cent.

Radopholus similis was previously a problem in some areas in Fiji. A survey in 2007 found *Radopholus similis* was the dominant nematode on farms in Muanaweni and Veikoba (Turaganivalu *et al*. 2013). Sampling from these same fields was undertaken in June and September 2014, but no *Radopholus similis* were present. Further sampling of volunteer ginger and weeds such as crowsfoot in the Veikoba fields was done again in February 2015. No *Radopholus similis* were found in any of the subsequent samples tested.

Nematode testing of ginger imported in the 2014 season

To monitor the efficacy of phytosanitary measures and procedures, the department undertook additional testing of all imported ginger consignments for the presence of pest nematodes. Rhizome samples were sent to independent laboratories in South Australia (University of Adelaide), Victoria (Crop Health Services, Department of Environment and Primary Industries) and Canberra (CSIRO Black Mountain) to extract and identify any nematodes present. No *Radopholus similis*, live or dead, were found in any of the samples tested. No other nematodes of quarantine concern were detected (see Table 1, page 9).

The results of the nematode tests of ginger consignments imported from Fiji were discussed in chapter 2.

4 Review of the quarantine status of Fiji's *Radopholus similis*

Australia provisionally recognised a possible intraspecific variant of *Radopholus similis* present in Fiji as a quarantine pest in the final IRA report, published in 2013.

Internationally, *Radopholus similis* appears to be a variable species, attacking different hosts in different places, with differing pathogenic effects reported on those hosts. It is not clear whether such differences are physiological or genetic, due to environmental influences or different host responses. Experimental data is limited as much of the understanding of host relationships and pathogenicity in *Radopholus similis* is based on pot experiments with limited replication and repetition. It is therefore difficult to extrapolate to infer cause and effect, and it has not been possible to scientifically demonstrate the cause of any observed differences.

With so many variables influencing nematode behaviour and reproduction rate, discerning the reason for apparent differences in disease expression is difficult. Pot experiments attempt to make direct comparisons of different isolates by standardising conditions, but behaviours observed under these artificial conditions may not reflect responses in the field. Also, given the high degree of *Radopholus similis* variability, even within a local population (Moens 2004; Costa *et al*. 2008), the representativeness of the isolate used in pot trials must be considered, particularly where cultures are reared from very small original samples (theoretically only a single female is required to start a culture, as males are not needed for reproduction).

A comprehensive review of the scientific literature was conducted. Summary findings are discussed below. Additional information on *Radopholus similis* is presented in Appendix 2.

Radopholus similis and plant disease

Radopholus similis is typically associated with plant roots. Adult females and juveniles usually penetrate the root near the tip, invading the cortical cells. They burrow between the cortical cells, puncturing the cell walls with their stylet to feed on the cytoplasm (Marin *et al*. 1998). Feeding destroys the cells, resulting in extensive cavities in the roots or other tissues. The nematodes migrate away from necrotic tissues, expanding the affected area as they tunnel within the roots to feed (Stirling and Stanton 1997). The root cavities coalesce to form dark red lesions, which turn black as other organisms invade the tissues (Stirling and Stanton 1997).

The key elements required for nematodes to be capable of causing disease in plants are the interaction of a sufficient population of virulent nematodes, a susceptible host and a favourable environment. Disease will not occur if any one of these three causal components is absent.

Whether *Radopholus similis* causes disease or not depends on the interaction between the number of nematodes attacking the host and the host's sensitivity (Blake 1968). Nematode numbers are influenced by factors such as the initial nematode population level in the soil or infested planting materials, the number of nematodes entering the roots, the attractiveness of the host roots, environmental factors such as temperature, soil type and moisture, and the nematode's reproductive rate (Blake 1968).

The aggressiveness or pathogenicity of *Radopholus similis* is related to its reproductive fitness, and therefore the rate of population growth in the plant tissues (Sarah *et al*. 1993; Fallas *et al*.

1995). The more rapidly the pest multiplies and the higher the population numbers that result, the greater the likelihood of host damage.

Why was *Radopholus similis* pathogenic on ginger in Fiji but not in Australia?

Radopholus similis has previously been a serious pest of ginger in Fiji, but is not known as pest of ginger in Australia. It has been found on Australian ginger at least once in the past, but did not reach damaging levels (Stirling 2014). While this lack of pathogenicity was attributed to the Australian nematodes being a different variant to the ones in Fiji (Stirling 2014), there are other plausible reasons for the different observed behaviour.

This section will discuss reported differences between *Radopholus similis* populations in Fiji and Australia, as well as the different field conditions that may account for the varied impacts previously observed on ginger. It will also consider the findings of pathogenicity experiments.

Differences in biological characteristics

Specific comparison of morphology and genetics of *Radopholus similis* populations in Fiji and Australia does not appear to have been researched. However, the previous published research on *Radopholus similis* in both countries does not report any atypical biological characteristics that would suggest the populations are significantly different to what is conventionally understood as *Radopholus similis*.

Morphology

Internationally there is considerable morphological variation reported between and among *Radopholus similis* populations (Xu *et al*. 2014). Within a population in Fiji, variations of around 15 per cent above and below the averages were reported in length, width, tail length and other physical characteristics (Taylor 1969a). These variations are similar to those reported in other populations by Koshy *et al*. (1991) and Xu *et al*. (2014). No physiological races or pathotypes of *Radopholus similis* can be distinguished according to morphological characters.

Differences in morphological characteristics are unlikely to be responsible for the differences in pathogenicity previously observed between nematode populations in Fiji and Australia.

Genetic differences

Insufficient molecular testing has been done to ascertain if the populations in Australia and Fiji are genetically the same. The internal transcribed spacer (ITS) DNA from some Australian isolates has been sequenced. Limited molecular research of nematode populations in Fiji has been undertaken and few results have been published or are available for comparison.

The available information indicates that Australia's *Radopholus similis* population shares the common worldwide haplotype (Tan *et al*. 2010), inferring that the nematodes in Australia originate from the same original source that was globally disseminated in the late nineteenth and early twentieth centuries (discussed further in Appendix 2). Little genetic diversity has been found among the Australian isolates sequenced (Tan *et al.* 2010). This suggests that there have been relatively few introductions of *Radopholus similis* into Australia, possibly only one, although it was probably introduced on a few occasions, either from the same source region, or from multiple sources with populations sharing a common origin.

Given that the *Radopholus similis* in Australia is thought to have been originally introduced from Fiji, it is not unreasonable to assume that at least some of the *Radopholus similis* in Fiji are genetically the same as those found in Australia. However, in the absence of a more complete understanding of the genetic diversity amongst Fiji's population, it cannot be ruled out that genetically different *Radopholus similis* have been introduced to Fiji from another source at some time in the past.

Nevertheless, unless there is a significant difference in pathogenicity attributed to specific genetic differences, genetic variation in itself does not provide sufficient grounds to regulate an organism as a quarantine pest. In the case of *Radopholus similis*, no genetic basis for apparent differences in relative aggressiveness has been identified (Kaplan *et al*. 2000; Hahn *et al.* 1996). While no specific 'pathogenicity gene' is known to exist, it is possible that some genetic differences may confer better survival abilities under particular conditions, permitting faster population growth and thereby greater damage potential. However, this remains speculative, and has not been conclusively demonstrated.

The absence of a clear link between biological difference and pathogenicity suggests that host or environmental factors may be more likely determinants influencing the reproductive rate and resulting disease caused by *Radopholus similis*. There are a number of significant differences in the environmental conditions and ginger production practices between Fiji and Australia.

Host differences and ginger varieties

Variation in the degree of susceptibility of different hosts to *Radopholus similis* has been reported in the scientific literature, with some hosts exhibiting little injury while others are severely damaged (Thorne 1961). The host association of *Radopholus similis* with ginger in Fiji is not unique in an international context, and ginger is widely recognised as a good host (Milne and Keetch 1976). It has been reported in ginger in a number of other places including Florida (Koshy and Bridge 1990), Hawaii (Sher 1968; Sipes *et al*. 2001) and India (Sundararaju *et al*. 1979).

While there are many different ginger varieties grown globally, commercial ginger production in both Fiji and Australia is almost exclusively limited to the same two types: 'Queensland' and 'Canton'. The Queensland variety is the main cultivar grown in Australia for processing, and is also the most common ginger variety planted in Fiji. In both Australia and Fiji, Canton is the main cultivar grown for the fresh market, although some of the Queensland variety is also sold fresh for consumption.

Therefore, host differences do not appear to be a contributory factor in the apparent differences in *Radopholus similis* pathogenicity reported on ginger between Fiji and Australia.

Differences in crop production practices

There are differences in ginger farming between Fiji and Australia, given the different industry structures, land ownership, farm size and labour costs. In particular, historically there have been significant differences in crop production standards, diligence in undertaking pest management practices and maintaining crop hygiene.

In Fiji, *Radopholus similis* became a pest of ginger when commercial production moved onto land previously used for growing bananas (Vilsoni *et al*. 1976). It was subsequently sustained by poor

crop production practices that ensured that pest populations remained in the field or were reintroduced into new crops each season. In the 1990s government assistance and oversight was intermittent and with declining export opportunities there was neglect of maintaining production standards (Gonemaituba 2008). Processing factories in Fiji typically bought ginger produced by the farmers regardless of the quality (Hogarth 1999), so there was little incentive to invest in crop improvement.

It is evident that improving crop production practices in Fiji has had a significant impact on reducing disease associated with *Radopholus similis* in their ginger crop. Maintaining better standards of seed preparation and crop hygiene has meant that pest populations have been suppressed to below detectable levels, or possibly even eradicated from some areas.

In Australia, root knot nematodes (*Meloidogyne* spp.) have long been economically damaging pests in ginger production (Pegg *et al*. 1974). The industry was also devastated by bacterial wilt outbreaks in the 1960s and 70s, which was introduced in infected seed material from China. More recently there have been significant disease problems with rhizome rots in ginger caused by *Pythium myriotylum*. (Stirling *et al*. 2009). Various control measures, including seed treatment, crop rotation and soil fumigation, have been practised over many decades to mitigate serious pests and diseases. The structure of the Australian ginger industry also assisted in maintaining and improving production standards. Historically almost all the ginger crop was purchased for processing by Buderim Ginger, which set the required quality standard (Hogarth 1999). While there were still quality problems at times, tight regulations on provision of seed, the introduction of volume-based quotas and bonuses for producing premium grade ginger all helped improve the overall standard of ginger production in the Australian industry.

The decline of *Radopholus similis* in Fiji's ginger crop highlights that farming practices and crop management are key factors influencing nematode population numbers, and as a consequence, economic damage. It is considered likely that the measures practiced by Australian ginger growers would also have had some impact in suppressing the *Radopholus similis* population if the pest had been introduced into the ginger crop. Therefore the differences in pathogenicity previously observed between populations in Fiji and Australia could be attributed to different crop production practices in both countries.

Climatic differences

There are important climatic differences between tropical Fiji and Australia's subtropical ginger growing regions, most notably temperature and rainfall patterns. This will have an impact on the relative ability of the pest to establish and maintain a population, the relative population numbers and growth rate, and the capacity to cause damages of economic concern.

Temperature is a key environmental factor that influences the distribution of *Radopholus similis* populations. *Radopholus similis* is sensitive to low temperatures. Its thermal preference is for warm conditions, and optimum temperatures are in the range of 24 to 32 degrees Celsius, with maximum reproduction occurring at about 30 degrees Celsius. Reproduction typically ceases at temperatures below about 16–17 degrees Celsius (Walker 2007).

Climatic conditions in Fiji's ginger growing region

Fiji has a tropical maritime climate. Fiji's ginger production is mostly in the wetter parts of the island of Viti Levu, particularly around Suva, Nausori and Navua. Due to the influence of the

surrounding ocean, the daily and seasonal temperature fluctuations in Fiji are relatively small. Irrigation is not typically used in Fiji's ginger production, so rainfall is an important factor influencing nematode survival.

Fiji's monthly mean maximum temperatures are within the optimum temperature range (25 to 32 degrees Celsius) for *Radopholus similis* development and reproduction for the entire year. The rainfall occurring from October until May also provides near ideal conditions for *Radopholus similis* population growth, with the wet conditions largely coinciding with the ginger growing season in Fiji.

Climatic conditions in Australia's ginger growing region

Australia's main ginger growing region is located in Queensland's Sunshine Coast hinterland, mostly within 50 kilometres of Yandina, including Eumundi and Nambour. Ginger is also grown around Gympie, and further north near Bundaberg. These areas have warm subtropical climates, but can experience occasional frosts in the winter months. Very little ginger has been grown commercially in tropical Australia. Rainfall at Nambour is around 1600 millimetres per year, although most commercial ginger production uses supplementary irrigation (Stirling 2004).

In the subtropical parts of its Australian distribution, *Radopholus similis* is typically more numerous in the warmer months than in the cooler months (Pattison *et al*. 2002). It is also reported to be less pathogenic on banana in northern NSW than in tropical north Queensland (ABGC 2012; Pattison *et al*. 2002), indicative of slower population growth resulting in lower population numbers. It would be anticipated that population growth on ginger in subtropical areas would follow a similar pattern. However, ginger is mostly harvested within five to twelve months (Comacho and Brescia 2009), whereas nematode populations can build up over many years in perennial banana plantations.

In Australia, planting of ginger occurs from August until mid-October, with mid to late September being optimum (Comacho and Brescia 2009). Overnight temperatures in the southern areas of ginger production are still cool during this period, below levels considered optimal for *Radopholus similis* development. The slower population growth in the cooler months means that *Radopholus similis* populations may not reach numbers where they would have a significant impact on the ginger crop.

Different climatic conditions in the ginger growing regions of Australia and Fiji may be a contributing factor to account for the previously observed different impacts on ginger crops.

Other factors

There are a number of other factors that influence *Radopholus similis* survival, which could have a significant role in determining whether they cause disease in host plants at that particular location. These factors include the soil type, soil texture, the range of microorganisms and other nematode species present in the soil, and the amount of organic material in the soil.

While anecdotally some differences in these factors are noted between the ginger production regions of Australia and Fiji, there is insufficient information to make an informed comparison and ascertain if these differences could be significant.

Purported differences observed in pathogenicity experiments

Two independent experiments, of reported similar design, were undertaken to study the pathogenicity of Australian and Fijian *Radopholus similis* isolates on ginger. In the first experiment, a Fijian isolate (derived from ginger) was assessed for pathogenicity on Fijian ginger (Turaganivalu *et al* 2009; 2013). In the second experiment, an Australian isolate (derived from banana) was assessed for pathogenicity on Australian ginger (Cobon *et al* 2012).

Due to the observed differences between the two experiments, inference was made by Cobon *et al* (2012) that the Australian *Radopholus similis* isolate was less pathogenic on ginger than the Fijian isolate. This was the basis for the claim that the populations were significantly different.

Experimental design

An analysis of experimental design shows some potentially significant differences between the Australian and Fijian studies that may have influenced outcomes (Table 2). The first experiment was run in a screen house at Koronivia, Fiji, and the second was conducted in a glasshouse in Brisbane, Australia. These two locations are separated by more than 2800 kilometres, with a difference of nearly ten degrees in latitude. As a result, the two experiments experienced different temperatures, relative humidity and day length.

There was no standardisation of temperature, soil type, watering regime and light availability, even though *Radopholus similis* survival and reproduction is sensitive to temperature, soil texture and moisture. The young plants were inoculated at different stages of maturity in the two experiments; inoculation of relatively more mature plants may influence susceptibility to nematode attack and observed pathogenicity. Different extraction techniques were used in the two experiments. In the Fiji experiment, nematodes were collected from macerated rhizomes on an extraction tray. The Australian experiment used a misting chamber to extract the nematodes.

Table 2 Comparison of conditions in the Australian and Fijian pathogenicity experiments

Country	Experimental conditions
Australia	Two litre pots with two parts washed river sand, one part peat moss, autoclaved 30 minutes at 65 °C Temperature range 19–31 °C (average 24 °C) Seed-piece about 60 g Inoculated with 1,500 nematodes after 12 weeks growth Four treatments of ten replicates (un-inoculated/inoculated, harvested after further 16/20 weeks) Total duration of experiment 32 weeks
Fiji	Four litre pots with two parts washed river sand, one part potting mix, autoclaved 30 minutes at 70 °C Temperature range 26 ± 3 °C Seed-piece about 55 g Inoculated with 1,500 nematodes after six weeks growth Four treatments of five replicates (un-inoculated/inoculated, harvested after further 15/20 weeks) Total duration of experiment 26 weeks

Both experiments showed extreme variability in nematode numbers between replicates under supposedly identical conditions. Considering the observed variability, the experimental design of both the Australian and Fijian studies indicates that additional replication within the experiments was required.

The lack of comparable factors, including the use of nematode isolates from different hosts and absence of appropriate control treatments, permits only superficial comparison between the two studies.

The department has just been informed that a repeat of the Australian experiment has been completed, but this data was unavailable for analysis prior to the release of this draft report. However, the department is committed to review any additional relevant information that becomes available.

What do the experiments tell us?

The Fijian experiment demonstrated that most of the plants inoculated with *Radopholus similis* were significantly diseased, indicating that the isolate was pathogenic under the experimental conditions.

The Australian experiment showed that the *Radopholus similis* isolate did invade the roots and rhizomes, but did not reduce the biomass of either seed pieces or rhizomes, and did not multiply readily on ginger under the experimental conditions.

While there were no above ground effects reported in the published Australian experiment, the unpublished results indicated that there were significant impacts on the number of shoots, shoot length and shoot mass. After 20 weeks the inoculated plants had fewer shoots than the controls (2.6 and 4, respectively), as well as reduced shoot length (35 per cent decline) and dry mass (25 per cent decline) in comparison with the controls. By 16 weeks there was already a 26 per cent decrease in root mass compared with the controls.

Collectively, the lack of replication and differences in experimental design warrant that a considerable degree of caution be placed on any interpretation of the data and any conclusions reached within and between these studies.

Determination on the quarantine status of *Radopholus similis*

It is important to note that as the international scientific community does not currently recognise the existence of a pathogenic, ginger-specific variant of *Radopholus similis*, if Australia wants to regulate such an organism the onus is on Australia to demonstrate conclusively that such a variant exists, consistent with its international treaty rights and obligations. A scientifically robust, defensible case must be made with clear evidence that would be accepted by experts. At this time there is not sufficient scientific evidence to support the claim that Fiji has a strain of *Radopholus similis* with significantly different pathogenicity on ginger compared to *Radopholus similis* already present in Australia.

The department and technical experts nominated by the Australian ginger industry, QDAF and Fiji all agree that the only way to scientifically prove such a difference would be to conduct an experiment comparing Fijian and Australian *Radopholus similis* isolates side-by-side in an appropriately controlled trial using a methodology agreed by all parties. A potential experiment was proposed in the QDAF submission of 19 December 2014, and was discussed further in the teleconference with QDAF and Fiji on 20 January 2015 and the meeting with QDAF in Brisbane on 3 March 2015. The department is prepared to reconsider the quarantine status of *Radopholus similis* if a significant biological difference can be scientifically proven in this way.

The Fijian authorities indicate that no live *Radopholus similis* cultures sourced from ginger are being held in Fiji and it may be difficult to source new specimens from the field considering its current reported low prevalence.

5 Proposed conditions for importation of ginger from Fiji

The efficacy of the phytosanitary measures and operational procedures in the first season of ginger imports was discussed in chapter 2. It was identified that phytosanitary inspection alone has not proven effective in ensuring that all consignments were free of *Aspidiella hartii* (yam scale).

The department has also determined that there is insufficient evidence to support the claim that the *Radopholus similis* in Fiji is significantly different to the one present in Australia, and the provisional quarantine pest status cannot be sustained.

Revised biosecurity measures for the importation of fresh ginger from Fiji are therefore proposed.

Proposed revised biosecurity measures

As *Radopholus similis* will no longer be regulated as a quarantine pest, the phytosanitary measures for this pest will be removed from the revised import conditions. Given this, the issue of the efficacy of methyl bromide fumigation against *Radopholus similis* in ginger is no longer relevant and is not considered further in this report.

Current import conditions require imported ginger to be free of *Aspidiella hartii*, but the finding of scales during quarantine inspections indicates that this requirement has not been met. Therefore, an additional phytosanitary measure will be required to mitigate the risk of live *Aspidiella hartii* being present in imported ginger. It is proposed that all ginger consignments are subject to mandatory methyl bromide fumigation for *Aspidiella hartii* at the rate of 32 grams per cubic metre for three hours at 21 degrees Celsius. Methyl bromide is a widely used fumigant against insect pests for quarantine purposes, because it is fast acting, killing most insects within 24 hours of exposure (Fields and White 2002; Macdonald and Reichmuth 1996). The efficacy of the fumigation treatment against *Aspidiella hartii* was confirmed in the ginger consignments previously imported from Fiji, where all yam scales found on imported ginger were confirmed dead.

With the addition of methyl bromide fumigation for *Aspidiella hartii*, no significant changes to the existing operational procedures are required, as the fumigation treatment was previously in place for *Radopholus similis*.

Future reviews of phytosanitary measures

Australia reserves the right to review and amend import policy or phytosanitary measures if circumstances change. A review may be triggered by changes in compliance with conditions, changes in the pest status in Australia or Fiji, new information relevant to pest risks, and any changes in the availability or efficacy of phytosanitary measures.

While it is proposed that *Radopholus similis* is removed as a quarantine pest, other import requirements such as grower and packhouse registration, and freedom from soil, roots and other contaminants will remain in place.

6 Acknowledgements

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Appendix 1 Assessing biosecurity risks and determining import policy

The objective of Australia's biosecurity policies is the prevention or control of the entry, establishment and spread of pests and diseases that could cause significant harm to people, animals, plants and other aspects of the environment. These policies are guided by international rules and standards, as well as domestic legislation.

International context

The World Trade Organization (WTO) is an international body that deals with the global rules of trade between nations, including quarantine regulations. Its main function is to ensure that trade flows as smoothly, predictably and freely as possible. As a nation that exports around two thirds of its agricultural produce, Australia benefits from the WTO's system of rules-based trade.

The SPS Agreement

The multilateral trading system is underpinned by agreements that are negotiated and signed by the world's trading nations, which provide the legal ground-rules for international commerce. Quarantine and import policy are governed by the Agreement on the Application of Sanitary and Phytosanitary Measures (also known as the SPS Agreement). This agreement sets out the rules that apply to all sanitary (human and animal health) and phytosanitary (plant health) measures that affect international trade.

The basic aim of the SPS Agreement is to maintain the sovereign right of any government to provide the level of protection it deems appropriate, but to ensure that these sovereign rights are not misused for protectionist purposes, creating unnecessary barriers to international trade. All governments accept that some trade restrictions may be necessary to ensure food safety and protection of animal and plant health (WTO 1998).

The SPS Agreement identifies which factors should be taken into account in the assessment of the risk involved. Measures to protect the health of animals and plants should be based as far as possible on the analysis and assessment of objective and accurate scientific data. A government can challenge another country's food safety or animal and plant health requirements on the grounds that they are not justified by scientific evidence.

Under the agreement, countries must establish phytosanitary measures on the basis of an assessment of the actual risks involved, and, if requested, make known what factors they took into consideration, the assessment procedures they used and the level of risk they determined to be acceptable. Australia's IRA process and publication of the final IRA report usually fulfils this obligation. In the case of fresh ginger from Fiji, Australia provisionally declared *Radopholus similis* to be a quarantine pest, pending provision of further evidence, which is presented in this review report.

The SPS Agreement defines the concept of an 'appropriate level of sanitary or phytosanitary protection (ALOP)' as the level of protection deemed appropriate by the WTO Member

establishing a sanitary or phytosanitary measure to protect human, animal or plant health within its territory.

The Australian Government, with the agreement of all state and territory governments (PIMC 2002), has articulated Australia's ALOP in qualitative terms. Whilst it is not currently expressed in the *Quarantine Act 1908*, ALOP is articulated in the *Biosecurity Act 2015*. Australia's ALOP is expressed as providing a high level of sanitary and phytosanitary protection aimed at reducing risk to a very low level, but not to zero. Where pests are assessed to have an unrestricted risk estimate that exceeds Australia's ALOP, risk management measures are required to reduce this risk to a very low level.

International Standards for Phytosanitary Measures (ISPM)

To harmonize sanitary and phytosanitary measures as much as possible, countries should base their sanitary or phytosanitary measures on international standards, guidelines or recommendations. Plant health standards, known as International Standards for Phytosanitary Measures (ISPM) are managed by the International Plant Protection Convention (IPPC), a multilateral treaty on the application of phytosanitary measures by governments to protect their plant resources from harmful pests that may be introduced via international trade. These standards are negotiated by IPPC member countries, including Australia. Presently there are 36 adopted ISPMs, providing guidelines on a range of topics including pest free areas (ISPM 4), phytosanitary certification (ISPM 7), pest risk analysis (ISPM 11), use of integrated systems approaches for pest management (ISPM 14) and inspection procedures (ISPM 23).

Regulated versus non-regulated pests

Under *ISPM 11: Pest Risk Analysis for Quarantine Pests* (FAO 2013b), pests cannot be considered for regulation in international trade unless they first meet the IPPC definition of a quarantine pest. The FAO defines a quarantine pest as 'a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled' (FAO 2013a). Official control is 'the active enforcement of mandatory phytosanitary regulations and the application of mandatory phytosanitary procedures with the objective of eradication or containment of quarantine pests' (FAO 2013a).

Pest risk assessments

The department conducts its risk assessments in accordance with internationally agreed standards, including ISPM 11 (FAO 2013b). According to ISPM 11:

> The taxonomic unit for the pest is generally species. The use of a higher or lower taxonomic level should be supported by scientifically sound rationale. In the case of levels below the species, this should include evidence demonstrating that factors such as differences in virulence, host range or vector relationships are significant enough to affect the phytosanitary status (FAO 2013b).

Pests that are already present in Australia, which are not subject to official eradication or control measures within Australia, cannot be regulated as quarantine pests.

Scientific rigour and quality of evidence required

The Department of Agriculture is not a research organisation, and does not have the capacity to undertake significant original research. Therefore it relies on information in the public domain, or provided by third parties. In general, the department relies on published peer-reviewed scientific literature and well established concepts to determine pest status.

Australia's biosecurity legislation

National laws relating to biosecurity are contained in the *Quarantine Act 1908* and subordinate legislation including the *Quarantine Regulations 2000*, the *Quarantine Proclamation 1998*, the *Quarantine (Christmas Island) Proclamation 2004* and the *Quarantine (Cocos Islands) Proclamation 2004*. The *Biosecurity Act 2015* along with supporting legislation was passed by the Parliament on 14 May 2015. Until commencement of the new legislation, the *Quarantine Act 1908* remains the primary piece of biosecurity legislation in Australia. *The Biosecurity Act 2015* will then replace the *Quarantine Act 1908*.

The *Quarantine Act 1908* provides the legislative basis for human, plant and animal biosecurity activities in Australia. It is administered jointly by the Australian Government Departments of Agriculture and Health on behalf of the Ministers for Agriculture and Health. It has broad coverage over matters of biosecurity concern and provides a national approach to biosecurity management at Australia's international borders to prevent the entry of quarantine pests and diseases on imported goods and conveyances. The *Quarantine Act 1908* provides for certain matters to be dealt with in more detail in regulations, proclamations and determinations.

The *Quarantine Act 1908* does not allow for the imposition of measures for insects or pathogens that are not determined to be quarantine pests, such as pests that are already known to be present in Australia and not under official control. Non-quarantine pests are regularly detected on imported consignments, but it would be a contravention of the Act for department officers to direct treatment for pests that are not a quarantine pest.

The importation of some goods is, by law, subject to certain conditions. These conditions are regulated by the *Quarantine Proclamation 1998* and communicated administratively using ICON, the department's import conditions database. Goods are only allowed into Australia if they meet the specified biosecurity import conditions, which may include the granting of an import permit by the department.

The importation of fresh ginger requires an import permit. The department will assess the permit application and, on the basis of that assessment, may decide to grant an import permit subject to any conditions deemed necessary for biosecure importation, use and disposal of those goods. The import permit specifies any import conditions to be imposed on imported products, taking account of the measures set out in an IRA.

The import risk analysis for ginger from Fiji

Initiation

In 2003, the Fiji Government submitted a formal request for market access to export fresh ginger to Australia. The department already had a significant number of import requests from other countries on its work program, and was unable to commit resources to an IRA for fresh

ginger from Fiji at that time. Some preliminary scoping work was undertaken to ascertain the potential pest risks.

Changes to the department's IRA process were introduced in amendments to the *Quarantine Regulations 2000* on 6 September 2007. This involved the regulation of key steps of the process, and additional transparency and stakeholder engagement. The department informed the Australian Ginger Growers Association (now known as AGIA) on 12 September 2007 that Australia may consider a proposal to assess ginger imports from Fiji in the 'short to medium term'. The industry wrote to voice their concern and requested that the industry and the Queensland Department of Primary Industries be consulted during the IRA process.

In preparation for commencing the IRA, the department sent a plant pathologist and biosecurity officer to Fiji in late September 2007 to observe ginger production and the export pathway. This was to gain a better understanding of the typical conditions in the field, the production methods used and the types of pests encountered.

Following a request through Growcom, the department provided AGIA with information about the proposed IRA process and timelines in January 2008. The department again contacted AGIA in early 2010 to notify it that a formal announcement on the commencement of an IRA for ginger from Fiji would be made shortly, and encouraged AGIA to provide any technical information it felt would assist in the assessment of pest risks. The department received a number of papers on ginger pests from AGIA in July 2010.

Commencement of the IRA process

Commencement of the Fiji ginger IRA was formally announced on 13 August 2010. Subsequently the department received correspondence from AGIA, Buderim Ginger and individual ginger growers outlining their concerns. AGIA later provided additional information about pests and diseases of concern to Australian growers for inclusion in the IRA. Responses from the department outlined the steps of the IRA process and identified opportunities for stakeholder comment, and indicated that the department would consider any additional information from stakeholders in its assessment.

A draft pest list and categorisation table was distributed to the relevant state departments in June 2011 for comment to identify any significant concerns prior to the release of the draft IRA report. Submissions were received from Queensland, South Australia, Victoria and Western Australia and the issues raised were given consideration in preparation of the draft report. In September 2011, department officials met with AGIA and QDAF at the Maroochy Research Facility in Nambour, Queensland to discuss the IRA process and the pests of quarantine concern identified during the pest categorisation process.

In October 2011, AGIA wrote to the department regarding the categorisation of a number of pests that are present in Australia. AGIA claimed that since these organisms had not been recorded on ginger in Australia, research needed to be undertaken to determine whether or not the Fiji organisms are more virulent than those found in Australia. An experimental study was proposed to examine differences in pathogenicity.

In November 2011, the department responded to AGIA indicating the proposed study would not provide meaningful inference on the comparative pathogenicity of Australian and Fijian isolates

of the microorganisms identified. In the absence of any other evidence for differences between the organisms in Australia and Fiji, the Chief Executive of Biosecurity Australia determined there were insufficient grounds to 'stop the clock' on the IRA process.

In December 2011, AGIA again wrote to the department and reiterated its request to halt the IRA process. The department again declined the request, and referred the issue of potentially different strains of the pests to the then Plant Biosecurity Principal Scientist for advice. AGIA also wrote to then Agriculture Minister, the Hon. Senator Joe Ludwig, to request his overview of the IRA process and to request that the department take note of the science being provided by industry.

Stakeholder consultation and release of the IRA report

The *Draft import risk analysis report for fresh ginger from Fiji* was released on 16 April 2012 for a 60-day public comment period. In May 2012, during the public consultation period, the department met with AGIA and QDAF in Brisbane to discuss the draft report and stakeholder submission process. Ten stakeholder submissions were received, including responses from AGIA, QDAF, Buderim Ginger and Growcom.

The department again met with AGIA and QDAF in July 2012 to discuss the issues identified in their submissions and how these issues would be addressed in the final report. QDAF provided information about a preliminary study it had undertaken that indicated that was a possibility that *Radopholus similis* in Fiji was exhibiting higher pathogenicity on ginger. The department subsequently requested additional information from QDAF, NSW DPI and CSIRO in June, July and August 2012 prior to finalising the provisional final IRA report.

The *Provisional final import risk analysis report for fresh ginger from Fiji* was released on 10 August 2012 for a 30 day appeal period. No appeals were received during this period. An inquiry by the Senate Rural and Regional Affairs and Transport references Committee was announced on 19 September 2012, with the department attending a Senate hearing on 23 October 2012.

The *Final import risk analysis report for fresh ginger from Fiji* was released on 22 January 2013. The report considered 65 pests and pathogens associated with ginger, nine of which were considered to be quarantine pests requiring detailed risk assessments. *Aspidiella hartii* (yam scale) was assessed to be above Australia's appropriate level of protection. *Radopholus similis* – putative intraspecific ginger variant (Fiji burrowing nematode), was provisionally considered to be a quarantine pest, pending further research. It was assessed to be above Australia's appropriate level of protection. Additional phytosanitary measures were specified to mitigate the risk of these pests entering Australia.

Import conditions for fresh ginger

The department audited Fiji's export system in October 2013 and subsequently agreed on the work plan with Fiji. Import permit conditions were then developed to permit ginger from Fiji, taking account of measures specified in the final IRA report and operational requirements contained in the work plan. These conditions were finalised in August 2014 and published on the department's import conditions database (ICON).

Conditions for Importation of fresh ginger from Fiji (August 2014)

Non-Commercial

1) The conditions under the Commercial section apply.

Commercial

Permitted commodity

1) Ginger rhizomes must be free of shoots, roots, soil and any other contaminants.

Document requirements

Import permit

2) An Import Permit is required and must be valid at the time the goods are imported into Australia.

Phytosanitary certificate

3) A Phytosanitary certificate issued by Biosecurity Authority Fiji (BAF) must accompany each consignment exported to Australia.

The following additional declaration must be provided in the Phytosanitary certificate:

> This consignment of ginger has been grown and packed in Fiji in accordance with the conditions governing entry of fresh ginger to Australia

4) Produce fumigated pre-shipment in Fiji must have the following details recorded in the treatment section of the Phytosanitary certificate, or treatment certificate referenced to the Phytosanitary certificate:
   - Dosage
   - Treatment duration
   - Flesh and chamber air temperature of fumigation (°C)
   - Name of the registered fumigation facility in the 'Additional Information' section.
5) For sea freight shipments, the container/s and seal number/s must be recorded on the Phytosanitary certificate.

Additional product requirements

6) All fresh ginger for export to Australia must be sourced from commercial export farms registered with BAF.
7) All ginger for export to Australia must be processed and packed in packinghouses registered with BAF.
8) All fresh ginger for export to Australia must be fully cleaned and air dried.

Mandatory fumigation requirements

9) All consignments of fresh ginger are subject to mandatory fumigation (pre-shipment or on arrival) with methyl bromide for the management of the Burrowing nematode – ginger variant (*Radopholus similis*) at one of the following rates:

a) 32 grams per cubic metre for three hours at 21 °C and above (flesh temperature)

b) 40 grams per cubic metre for three hours at 15.0 °C to 20.9 °C (flesh temperature)

c) 48 grams per cubic metre for three hours at 10.0 °C to 14.9 °C (flesh temperature).

Pre-shipment fumigation

10) Pre-shipment fumigation can only be undertaken in facilities that have been registered by BAF.

On arrival fumigation

11) Only ginger that has been produced in accordance with the conditions governing the entry of fresh ginger into Australia will be permitted to undergo fumigation on arrival in Australia.

12) Shipping seals for sea freight must remain intact until checked by the Department of Agriculture at the fumigation facility.

13) Where consignments are imported for on arrival fumigation, fumigation must be completed before Department of Agriculture inspection at a Department of Agriculture approved fumigation facility.

14) Security of the consignments must be maintained at all times during transport from the port/airport to the fumigation facility, and during transfer of the ginger from the container to the fumigation chamber to ensure entry or exit of pests is minimised.

15) All ginger must be kept segregated from any other imported or domestic produce until it is cleared by the Department of Agriculture.

Packaging and labelling requirements

16) Consignments can be air or sea freighted to Australia.

17) If the consignment is exported by sea freight, a numbered seal must be placed on the loaded container door by an authorised officer from the Fijian authorities and the seal number along with the container number entered on the Phytosanitary certificate.

18) The packaging must be synthetic or highly processed if of plant origin. No unprocessed plant material such as straw must be included in the packaging.

19) Individual cartons must be labelled and be identified by the packing facility name or BAF reference code.

20) The following information must be printed on each carton in the consignment:

a) Product name

b) Date of packing

c) Name or registration reference for the fumigator/facility (for pre-shipment fumigated consignments)

d) Date of fumigation (for pre-shipment fumigated consignments)

e) Packhouse registration number

f) Name of the exporting company

21) One of the following secure packaging options must be used to maintain the quarantine security of goods arriving in Australia.

a) Produce may be packed in integral (fully enclosed) cartons (packages) with boxes having no ventilation holes and lids tightly fixed to the bases.

b) Cartons (packages) with ventilation holes must have the holes covered/sealed with a mesh/screen of no more than 1.6 millimetres pore size and not less than 0.16 millimetres strand thickness. Alternatively, the vent holes could be taped over.

c) Vented cartons (packages) with sealed polythene liners within are acceptable (i.e. produce packed in polythene bags - folded polythene bags are acceptable).

d) Produce transported in sealed containers - Cartons (packages) with holes as loose boxes or on pallets may be transported in sealed containers. The container must be transported to the inspection point intact.

22) Timber packaging, pallets or dunnage in containers or on flat racks will be subject to inspection and treatment on arrival, unless certified as having been treated by a department approved method. (Refer to the department's publication 'Cargo Containers: Quarantine aspects and procedures').

Inspection and/or clearance

23) All consignments will be inspected by the Department of Agriculture on-arrival in Australia.

24) Inspection must occur at the first port of call. No land-bridging of consignments will be permitted unless the goods have cleared quarantine.

Appendix 2 *Radopholus similis:* biology, behaviour and history

This section reviews the scientific literature on the biology and behaviour of *Radopholus similis*, and presents a brief history of the species in both Fiji and Australia.

Radopholus similis (Cobb, 1893) Thorne, 1949 (Tylenchida: Pratylenchidae)

Radopholus similis was first described by Nathan Cobb from the roots of diseased banana plants in Suva, Fiji (Cobb 1893). Samples collected in July 1891 were sent to Cobb in Sydney for investigation after a serious disease in the banana crop had been reported the previous year (Cobb 1915). At the time, nematodes were suspected as being a possible cause of the banana disorder, although the disease was subsequently attributed to bunchy top virus (Magee 1927). Cobb mistakenly described the males and females as two separate new species, *Tylenchus similis* and *Tylenchus granulosus*, respectively (Cobb 1893).

Agoston Zimmerman collected nematodes later identified as *Radopholus similis* from coffee roots in Java, Indonesia, in 1898 (Cramer 1957) and from stunted, wilted tea seedlings in 1899 (Morton 1964). Zimmerman originally described this nematode as *Tylenchus acutocaudatus*. Menzel subsequently synonymised *Tylenchus acutocaudatus* with *Tylenchus similis* in 1929 (Sher 1968).

In 1907 Cobb collected nematodes in diseased sugarcane roots on Kauai, Hawaii. The heavily infested roots had significant lesions and cavities, as well as blackened areas associated with secondary fungal rots. Although noting the similarity to those found earlier on banana in Fiji, Cobb believed the nematode to be a new parasitic species, and described it as *Tylenchus biformis* in 1909 (Cobb 1915). Similar nematodes were subsequently isolated from diseased banana rhizomes and stems in Jamaica in 1915. The banana plants were affected by a disorder known locally as black head, and had symptoms very similar to the diseased sugarcane in Hawaii. Cobb then determined the nematodes in Fiji, Hawaii and Jamaica were all the same species, and published a more detailed description using the original name *Tylenchus similis* (Cobb 1915).

Goodey (1933) considered the generic name *Anguillulina* to have priority over *Tylenchus*, resulting in the name *Anguillulina similis* being recognized in some literature. Gerald Thorne proposed a new genus, *Radopholus*, in 1949, making *Radopholus similis* the type species (Thorne 1949).

Radopholus similis now has a wide distribution, and is present in tropical and sub-tropical areas of Africa, Asia, the Americas, as well as Australia and the Pacific Islands (EFSA 2014). The international spread of *Radopholus similis* was a relatively recent event, probably starting in the late nineteenth century, assisted by human transport of infested banana corms and other plant material (Marin *et al*. 1998).

Lifecycle and behaviour of *Radopholus similis*

Radopholus similis is a migratory endoparasitic nematode, found in most tropical and subtropical regions of the world, particularly where bananas are grown (Tan *et al*. 2010; Marin *et al*. 1998). The lifecycle of *Radopholus similis* consists of the egg, four juvenile stages and the adult (Stirling and Stanton 1997). The lifecycle can be completed in as little as 20 to 25 days at 24 to 32

degrees Celsius (Stirling and Stanton 1997). On citrus, the lifecycle can be completed in 18 to 20 days under optimum conditions (Duncan and Moens 2006).

Each female lays around four to five eggs per day for two weeks (Marin *et al*. 1998), with the eggs reported to hatch in eight to ten days (Brooks 2008). On some hosts, eggs may hatch in two to three days under optimum conditions (Duncan and Moens 2006). The first juvenile stage develops within the egg, moulting before emergence as a second stage juvenile (Brooks 2008).

Both males and females are present in the population, and sexual reproduction is the norm, although hermaphrodism is an alternative reproductive strategy in *Radopholus similis*. Reproduction for at least three generations without males has been reported (Sher 1968). Self-fertilisation takes place around 50 to 60 days after the fourth moult in females that have not mated (Kaplan and Opperman 2000).

Population development is host-dependent (Duncan and Moens 2006). All life stages of *Radopholus similis* develop within the host tissue, although adults and juveniles can be present in the rhizosphere soil (EFSA 2014). Adult males have degenerate stylets and do not feed, so are unable to penetrate the root tissue (Loos 1962). However, they may still be found inside the roots if juvenile nematodes have undergone their final moult within the root tissue (Stirling and Stanton 1997).

Radopholus similis is typically associated with plant roots, but they can feed within the shoot tissues of some hosts such as anthurium, calathea and agloanema (Sipes *et al*. 2001). Adult females and juveniles usually penetrate the root near the tip, and can migrate along the length of the root. In banana they invade the cortical cells, and feed and reproduce within the cortex of the roots and corm. They burrow between the cortical cells, puncturing the cell walls with their stylet to feed on the cytoplasm (Marin *et al*. 1998).

Feeding destroys the cells, resulting in extensive cavities in the roots or other tissues. The nematodes migrate away from necrotic tissues, expanding the affected area as they tunnel further within the roots to feed (Stirling and Stanton 1997). The root cavities coalesce to form dark red lesions, which turn black as other organisms invade the tissues (Stirling and Stanton 1997). Secondary invasion by fungi, bacteria and microbivorous nematodes hastens the destruction of the roots (Marin *et al*. 1998). The female lays eggs in the decaying tissues (Brooks 2008).

Host range

Radopholus similis has a wide recognised host range, with more than 350 plant hosts reported (Brooks 2008) from over 50 genera (Sipes *et al*. 2001). It is associated with many economically important crop plants, particularly banana, but also black pepper, coconut, coffee, ginger, citrus, pineapple, sugarcane and tea, and is well known as a pest of foliage ornamentals belonging to the Araceae, Marantaceae and Zingiberaceae families (Queneherve 2009). It also survives on many weedy plant species that grow in the vicinity of crop species (Queneherve 2009).

Ginger is recognised as a good host of *Radopholus similis* (Milne and Keetch 1976), as are many other related plants in the Zingiberaceae family such as shell ginger (*Alpinia* spp.), ginger lily (*Hedychium* spp.) and turmeric (*Curcuma longa*). Significant damage to ginger has been reported in Hawaii (Sher 1968; Sipes *et al*. 2001), India (Sundararaju *et al*. 1979) and Fiji (Vilsoni *et al* 1976).

Radopholus similis has been found on ginger in Australia (Stirling 2014), but has not been associated with crop damage. An experimental trial by Cobon *et al*. (2012) demonstrated that an Australian isolate survived on ginger, although was not reported to cause significant damage.

Survival requirements and preferences

Like most plant parasitic nematodes, *Radopholus similis* populations are influenced by a number of environmental factors, such as temperature, rainfall, soil type and structure, topography and host availability (Duyck *et al*. 2012; Chabrier *et al*. 2010b). As a result, nematode numbers can vary significantly, both geographically and temporally, which influences the degree of pathogenicity and corresponding levels of economic damage.

Radopholus similis is an obligate parasite, and requires a living host to survive (Brooks 2008). Survival in the soil without hosts has variously been measured between two to three months (DuCharme 1955), up to six months (Tarjan 1961) or even longer in some soil types under certain conditions (Chabrier *et al*. 2010a). In the absence of a host plant, the nematode probably survives on pieces of living root scattered in the soil (Cohn 1972). Taylor (1969a) reported that no *Radopholus similis* were found in volunteer banana plants ten weeks after a heavily infested plantation in Fiji was destroyed. It was suggested that six months without any volunteer plants should result in few or no nematodes in the soil, and they would certainly have disappeared from the soil within a year (Taylor 1969a). *Radopholus similis* does not have a resting stage to survive periods of adverse conditions (Chabrier *et al*. 2010a).

Radopholus similis is sensitive to low temperatures, but thrives at higher temperatures and moist soil conditions (EFSA 2014). Development can occur at temperatures between 12 to 32 degrees Celsius (Cohn 1972; Duncan and Cohn 1990), although 25 to 32 degrees Celsius is considered optimum (Walker 2007). The reproduction rate of *Radopholus similis* is influenced by the soil temperature. They typically do not reproduce at temperatures below 16 to 17 degrees Celsius or above 33 degrees Celsius (EFSA 2014), with highest rates occurring between 25 and 30 degrees Celsius (Duyck *et al*. 2012). However, reproduction at 15 degrees Celsius has been reported in nematodes cultured from isolates collected from ornamental plants in Europe (Elbadri *et al*. 2001; Duncan and Moens 2006) that may have adapted to surviving in cooler conditions (EFSA 2014).

Plant parasitic nematodes are present in all soil types, but generally only exceed a certain population limit under specific soil conditions (O'Bannon and Tomerlin 1971). *Radopholus similis* populations build up most rapidly in deep, well drained sandy soils, followed by gravelly or loamy soils, but they do less well in shallow, poorly drained clay soils (O'Bannon and Tomerlin 1971; EFSA 2014).

Nematode abundance is influenced by the porosity of the soil, as movement of *Radopholus similis* is greatest in light textured soils (Duncan and Cohn 1990). Movement in the soil requires a film of water and soil pores of around 30 to 300 micrometres in diameter. These conditions rarely occur together in vertisol (clay) soils, perhaps only when rain occurs just after tillage (Duyck *et al.* 2012). Smaller pore sizes form a barrier to movement, as nematodes are unable to constrict to pass through narrow pore necks between soil particles (Wallace 1958).

Soil moisture influences the abundance of nematodes, with *Radopholus similis* preferring moist, but not saturated, soils. *Radopholus similis* can survive in water for several days, and submersion

in flooded soils for up to five weeks, but is sensitive to anoxia (absence of oxygen) (Chabrier *et al*. 2010a). In tropical regions, the abundance of *Radopholus similis* is known to decrease during the wet season (Duyck *et al*. 2012). Populations are also affected by extended dry periods. In Hawaii, *Radopholus similis* populations have been reported to decrease if rainfall over a three month period is greater than 1900 millimetres or less than 760 millimetres (Prasad 1972). Unlike some plant pathogenic nematodes, *Radopholus similis* does not have a resting or survival stage, and is generally considered to be a species with poor survival abilities (Chabrier *et al*. 2010a).

The soil closest to the surface is most affected by fluctuations in temperature and is more prone to moisture deficits, so nematode development in this zone can be inhibited (Duncan and Cohn 1990). The topsoil also has higher organic matter than deeper layers, and the presence of microorganisms such as *Fusarium oxysporum* and *Paecilomyces lilacinus* can promote biological suppression of *Radopholus similis* (Walker 2007; Chabrier *et al*. 2010a).

Intraspecific variation in *Radopholus similis* populations

Host preference

Apparent differences in host preference between *Radopholus similis* populations had been noted as early as 1931, and the possibility that there may be different physiologic races or strains was suggested (Goodey 1933). Marked differences in the abilities of various populations to transfer from one host to another have been reported, as well as the degree of susceptibility of different hosts, with some hosts exhibiting little injury while others are severely damaged (Thorne 1961).

The most studied host difference is the ability to feed on the roots of citrus trees. *Radopholus similis* was first identified as the causal agent of a citrus disorder in Florida known as 'spreading decline' in 1953, although the disorder had been reported as early as 1928 (MacGowan 1977). Pathogenic effects on citrus trees are not reported elsewhere, and experimental attempts to inoculate citrus with nematodes isolated from banana (Blake 1961), ginger (Vilsoni *et al.* 1976), anthurium (Huettel *et al*. 1986) and other known hosts have been unsuccessful. This is examined further in the discussion on pathotypes.

A population of *Radopholus similis* was identified from sweet orange roots in Tonga, during a survey on the island of 'Eua in 1976 (Orton Wiliams 1980). As the 'citrus pathotype' was not known to be present in the Pacific Islands, it was speculated that the citrus roots may have mixed with the roots of another host in the soil (Orton Williams 1980), although this is questionable. Bridge (1988) considered its parasitism on citrus in Tonga doubtful, but this does not appear to have been investigated further. An experimental trail by Blake (1961) demonstrated that Australian *Radopholus similis* isolates sourced from banana did initially invade citrus roots in similar numbers to banana and sugarcane roots. However they did not reproduce on citrus, and after 24 weeks no nematodes were recovered from the roots or soil (Blake 1961).

Other discrepancies in *Radopholus similis* host status are reported. Sugarcane has been variously reported as a good host (Prasad 1972), a poor host (Milne and Keetch 1976) and a non-host (Chabrier *et al*. 2010a). Koshy and Jasy (1991) found one variety of sugarcane was highly susceptible to *Radopholus similis*, but another variety was apparently immune.

Morphological variation

There is considerable morphological variation between and among *Radopholus similis* populations. Variation in a number of physical characters has been reported, including the number of female head annuli, shape of the female labial disc, terminal position of the female lateral lips, the number of genital papillae before the male cloacal aperture, and tail shape of both males and females (Xu *et al*. 2014).

Taylor (1969a) examined morphological variation within a population of *Radopholus similis* collected from banana plants in Fiji. The lengths of the stylets, spicules and gubernacula were remarkably constant, but variation of around 15 per cent above and below the averages were reported in length, width, tail length and other physical characteristics. There was more variation in the body shape in females according to the stage of development and whether they had eggs (Taylor 1969a).

Tarte *et al*. (1981) separated *Radopholus similis* into two groups, based on whether they had pointed or rounded tails. Individuals of both groups were present in all thirteen *Radopholus similis* populations examined in Ecuador, Panama, Costa Rica, Honduras, Guatemala and Mexico, but occurred at different frequencies. It was noted that rounded tailed females were more prevalent in the banana growing areas experiencing greater crop losses, with speculation that the nematodes with pointed tails may be less pathogenic (Tarte *et al*. 1981). This link between tail shape and aggressiveness has not been substantiated (Volcy 2011).

Koshy *et al*. (1991) examined morphometric variation in twelve *Radopholus similis* populations collected from coconut, arecanut, banana and black pepper in South India. Differences between populations were reported in all the morphological characters examined, with variations commonly around ten per cent of the average, but within previously reported values (Koshy *et al*. 1991).

Distinguishing particular sub-specific variants by morphological characteristics has not proven possible (Xu *et al*. 2014). Even the citrus and banana pathotypes, at one time considered to be separate species, are morphologically indistinguishable (Huettel *et al*. 1984).

Genetic variation

In most plant parasitic nematodes, species with intraspecific differences in host range, geographic distribution, reproduction rate or pathogenicity can be readily distinguished by genetic analysis. In the case of *Radopholus similis*, however, the genome is highly conserved, with considerable genetic similarity among isolates collected from different hosts in different geographic regions (Marin *et al*. 1999). No genetic basis for differences in host preference or relative aggressiveness has been identified in *Radopholus similis* (Kaplan *et al*. 2000).

Preliminary research on differential gene expression suggests a possible correlation between production of a cellulase enzyme and pathogenicity, which may vary between populations (Zhang *et al*. 2012). However, while gene expression may occur at different rates between populations, the reasons for that different expression are not yet clear.

Random amplified polymorphic DNA (RAPD) analysis has been used to compare differences in the genomes of different *Radopholus similis* populations. Hahn *et al*. (1996) compared DNA extracts of thirteen *Radopholus similis* populations to assess genetic divergence on different

hosts in different locations. Some genetic differences between isolates were apparent in the RAPD profiles, although overall a high degree of genomic similarity was observed. Hierarchical cluster analysis revealed two separate clusters with at least 86 per cent similarity (Hahn *et al*. 1996). Populations from banana in Cameroon and neighbouring Nigeria were similar, and the isolate from ginger in Fiji was most closely related to one from banana in the Cook Islands, suggesting some correlation between geographic proximity and genomic similarity. Conversely, a population from clove in Sri Lanka was most closely related to one from banana in Guadeloupe, while isolates from Ivory Coast and Guinea were in a different cluster to one from Nigeria (Hahn *et al.* 1996).

Fallas *et al*. (1996) identified two distinct genetic clusters amongst populations from different geographic regions around the world. A Queensland isolate was most closely related to one from Costa Rica, and was in the same cluster as other isolates from Nigeria and Cameroon. The other cluster included isolates from Guinea, Guadeloupe, Ivory Coast, Uganda and Sri Lanka (Fallas *et al.* 1996). No correlation could be found between apparent genomic similarity and geographic proximity, and within both clusters the isolates varied significantly in their reproductive fitness and pathogenicity on banana (Fallas *et al*. 1996).

Researchers have also examined nuclear ribosomal DNA (rDNA) sequences to compare different *Radopholus similis* populations. Kaplan *et al*. (2000) found no genetic variation that correlated with differences in host preference. Within the species, some molecular variation is reported (Elbadri *et al*. 2002; Costa *et al*. 2008), although the significance of this is not apparent.

Elbadri *et al*. (2002) found divergence between isolates of up to four per cent in the internal transcribed spacer (ITS) region of the rDNA of various populations. Phylogenetic analysis identified three separate clusters within the 25 isolates tested. However, divergence within these closely grouped isolates was on a similar scale to the divergence between isolates of different clusters (Elbadri *et al*. 2002). Costa *et al*. (2008) also found genetic variation between populations from the same region could be greater than differences between populations from geographically distant locations.

Tan *et al*. (2010) examined 94 isolates of *Radopholus similis* from many different hosts and geographic regions, finding up to 4.6 per cent differentiation in the ITS region of the rDNA amongst the 42 haplotypes identified. That study identified two main haplotype clusters: one of Southeast Asian origin, the other from Africa. Many populations worldwide share a common haplotype grouped within the Southeast Asian cluster (Tan *et al*. 2010), which is consistent with global dissemination of *Radopholus similis* via the trade in banana planting materials originally from Southeast Asia (Marin *et al*. 1998). All the Australian isolates examined by Tan *et al*. (2010) belonged to the common worldwide haplotype. The large diversity of other haplotypes within Southeast Asia suggests that *Radopholus similis* is native to that region (Tan *et al*. 2010). The separate cluster of populations in Africa indicates they may have been isolated from Asian populations for a long time (Tan *et al*. 2010).

Karyotypic differences

Differences in the number of chromosomes (karyotype) between three *Radopholus similis* populations in Florida were examined by Huettel and Dickson (1981), with nematodes from banana reported to have four chromosomes, while isolates from citrus had five. This was determined by removing the reproductive system from the nematodes and staining the

chromosomes in isolated ovaries, eggs and polar bodies with propionic orcein (Huettel and Dickson 1981). Similar findings were observed in Hawaii, where a population on banana was found to have four chromosomes, while those on anthuriums had five (Huettel *et al*. 1986), while another study of six isolates on banana, anthurium and calathea found chromosome numbers ranged between four and seven (Goo and Sipes 1999).

Doubts about the experimental methodology and interpretation of results were raised when a more accurate method revealed many other non-citrus parasitic populations all had five chromosomes. An analysis of 56 isolates from around the world using fluorescent nucleic acid-specific stains (DAPI or Hoechst 33258) found the five chromosome haploid karyotype present in all isolates (Kaplan and Opperman 2000). Further study of 20 *Radopholus similis* populations by Xu *et al*. (2014) found the haploid chromosome number in all populations was five.

Putative differences in karyotype between *Radopholus similis* populations cannot be supported (Kaplan and Opperman 2000), and it has not been possible to separate different pathotypes according to karyotype (Xu *et al*. 2014).

Differences in pathogenicity

Radopholus similis is well known as a pathogen of banana (Blake 1972), pepper (Thorne 1961), coffee (Cramer 1957), tea (Morton 1964), ginger (Sundararaju *et al*. 1979), arecanut (Sundararaju 1984), and many other hosts. However, the susceptibility of hosts is exceedingly variable, with some hosts exhibiting little or no injury, while others may be severely damaged (Thorne 1961).

Whether *Radopholus similis* causes disease or not depends on the interaction between the sensitivity of the host and the number of nematodes attacking that host (Blake 1968). The different virulence reported between burrowing nematode populations is due to the different numbers of nematodes parasitizing the host (Fallas *et al*. 1995). Nematode numbers are influenced by factors such as the attractiveness of the host roots, the initial nematode population level in the soil or infested planting materials, the number of nematodes entering the roots, environmental factors such as temperature, soil type and moisture, and the nematode's reproductive rate (Blake 1968).

Costa *et al*. (2008) demonstrated differences between populations in their capacity to reproduce and cause damage in three banana cultivars. While all twelve populations tested reproduced on all cultivars, significant differences in the reproduction rate were reported between banana cultivars and nematode populations. A degree of resistance to some of the nematode populations was reported in one of the cultivars, which reduced the reproduction rate. Faster growing populations initiate greater damage earlier, and hence have a more detrimental effect on plant growth (Costa *et al*. 2008).

Even though there is relatively little genetic diversity reported within the Australian *Radopholus similis* population surveyed on banana (Tan *et al*. 2010), different Australian isolates reportedly have varying levels of pathogenicity (Cobon and Pattison 2003). The presence of more than one pathotype in Australia has been speculated (Cobon and Pattison 2003).

Purported differences in pathogenicity on ginger between *Radopholus similis* populations in Fiji and Australia were discussed in chapter 4.

Pathotypes in *Radopholus similis*

Several terms to designate intraspecific variation in nematodes have been used in the past and inconsistently applied, including race, biotype, strain and pathotype (Dropkin 1988). Use of the term 'race' is inappropriate when describing variants of *Radopholus similis*, as this denotes a population with distinctive morphological or physiological characters. It also indicates some geographic or genetic isolation from other intraspecific variants (Dropkin 1988). The term 'biotype' denotes a distinctive population that has uniform genetics (Dropkin 1988), which is also not appropriate for describing variants of *Radopholus similis*, which has some diversity within populations. The term 'pathotype' applies to populations whose members can reproduce on a host that may be resistant or immune to other populations of the same nematode species (Dropkin 1988). Pathotype is more correctly applied to *Radopholus similis* variants because it denotes pathogenic specificity on a restricted range of host plants (for example, citrus).

The existence of a unique 'citrus race' of *Radopholus similis* was first raised by DuCharme and Birchfield (1956), who initially suggested there were three *Radopholus similis* races, based on the ability to parasitize roots of either citrus or banana, or both hosts. This was later revised to two races with extended overlapping host ranges; one that attacks citrus (citrus race), and one that does not (banana race) (Blake 1972; Esser *et al*. 1984). There was also speculation about the existence of other races with specific preferences for sugarcane and pineapple (Queneherve 2009). Based on different host preferences determined in experimental pot trials, Koshy and Jasy (1991) identified ten supposed 'races' in India. Hahn *et al*. (1994) reported that apparent genetic divergence identified by RAPD analysis of populations suggested there were three divergent biotypes in Sri Lanka on arecanut, tea and banana.

The 'citrus race' was elevated to species rank, as *Radopholus citrophilus*, by Huettel *et al*. (1984), based on putative biochemical, physiological and karyotypic differences and reproductive isolation (Huettel *et al*. 1984; Kaplan and Opperman 1997). However, this was subsequently rejected, as morphological structures supposedly unique to *Radopholus citrophilus* were also observed in *Radopholus similis* populations, and the ability of the two species to mate and produce offspring was demonstrated (Kaplan *et al*. 1997). Molecular analysis of the genomes indicated no significant difference between the two species (Kaplan *et al*. 2000), confirming that *Radopholus citrophilus* is an invalid species. The *Radopholus similis* found on citrus in Florida is now widely recognised as a pathotype, but the reason for this particular host preference remains unknown.

Citrus parasitism is only associated with *Radopholus similis* populations in Florida, but the citrus pathotype has also supposedly been reported from Hawaii, Cuba, Dominican Republic, Puerto Rico, Guyana, and the Ivory Coast (EPPO 1990; EFSA 2014). It is important to note that *Radopholus similis* has never actually been found on citrus in these other locations, and identifications as *Radopholus citrophilus* or the citrus pathotype of *Radopholus similis* were made using flawed comparisons of morphometrics, karyotype and electrophoretic isozyme patterns. Huettel *et al*. (1986) reported that the '*Radopholus citrophilus*' found on anthuriums in Hawaii was a non-citrus parasitizing pathotype. Such a description is inconsistent with the supposedly defining characteristic of the citrus pathotype.

Some doubt must be cast on whether the *Radopholus similis* in Florida really is a variant with a specific host preference for citrus. It may simply be that the particular local conditions in that region make citrus a susceptible host, whereas elsewhere the soil conditions are unsuitable for

significant nematode infestation of citrus. In Florida, *Radopholus similis* is only found on citrus in the Central Ridge and some neighbouring areas. The soils in this region are characterised by their extremely sandy texture (more than 95 per cent sand), and low levels of organic matter (less than 0.25 per cent) (Walker 2007). The nematodes there are found deeper in the soil profile, attacking the roots down to at least 3.7 metres depth, while fewer of the feeder roots closer to the surface are affected (Walker 2007). Away from the Central Ridge, where the sand content of the soil is lower, nematode damage to citrus is mild or absent (Walker 2007).

Origins of *Radopholus similis* and role of international trade in its spread

The genus *Radopholus* is considered to be native to Australasia, with the majority of the described species being present in Australia. However, the lack of genetic diversity within *Radopholus similis* populations in Australia suggests that this species was probably introduced from elsewhere, and most likely originated in Southeast Asia (Tan *et al*. 2010), possibly Malaysia (Marin *et al*. 1998). The spread of *Radopholus similis* from its centre of origin is largely attributed to human assistance associated with the expansion of banana production and the movement of banana planting materials in late nineteenth and early twentieth centuries (Marin *et al*. 1998). The popularity of the Cavendish banana resulted in its introduction to many new regions during that period, and cultivars with superior characteristics were subsequently sought and widely disseminated.

Australia has a long history of horticultural trade with Fiji. From the early 1800s until the 1930s, Fiji was a significant source of tropical foods imported into Australia. Large quantities of fresh bananas were exported to Australia, predominantly to Sydney and Melbourne, peaking in 1914 (Ng Kumlin Ali 2002) before trade protectionism measures, shipping difficulties and disease problems eventually made the trade unviable. Smaller volumes of other commodities were also regularly traded, including fresh ginger, turmeric, taro and coconuts. Fiji was also a supplier of planting materials for a number of tropical and subtropical crops.

The spread of a number of nematode species and other crop pests into new environments during this period is not surprising, as the movement of planting materials was essentially unregulated. There are numerous historical reports of various exotic plants being intentionally introduced into Australia and Fiji. While the volumes of plant materials involved were small in comparison with the contemporary nursery stock trade, the awareness of pest nematodes at the time was very poor, and there were no quarantine controls in place to prevent the movement of pests, diseases and soil with imported plants and planting materials.

Acclimatisation societies and botanical gardens actively facilitated the exchange of many crop and ornamental plants within the colonies of the British Empire. Among these traded plants were many that were later identified as hosts of *Radopholus similis*, such as banana, sugarcane, ginger, yams, taro, turmeric and anthuriums. Banana plants had already being introduced into Sydney by 1809 (*Sydney Gazette*, 9 July 1809), and there would have been many subsequent importations from different sources as growers tried to obtain superior varieties.

Radopholus similis in Fiji

The details about how and when *Radopholus similis* first arrived in Fiji are not known with any certainty. The Pacific Ocean provides an effective barrier to natural movement of nematode

pests into Fiji, so their introduction must have been assisted by humans. Many nematode species now present in Fiji were introduced in crops and ornamental plants in the 19th Century (Orton Williams 1980). A number of indigenous banana varieties had been introduced to Fiji during historical migrations of the Melanesian people (Daniells 1995), but there is no information to suggest *Radopholus similis* arrived with those plants. Importation is most likely to have occurred in infested Cavendish banana suckers from a source in Southeast Asia some time prior to 1890.

Cavendish banana suckers were first brought to Fiji in 1848 from plants introduced to Samoa in 1838 (Fawcett 1913). Fiji established a commercial banana industry around 1877, with production initially based around the Cavendish variety now known as dwarf Cavendish, but then known locally as 'China' (Taylor 1969b), which may give a clue as to its origin. Alternatively, this may simply reflect the fact that Chinese residents initially dominated the Fiji banana trade (Ng Kumlin Ali 2002).

Radopholus similis was first reported in Fiji in July 1891, collected from the roots of dwarf Cavendish plants growing next to Government House in Suva (Taylor 1969b). This site was a small experimental plantation, which was established to examine a disorder that had been observed in the banana crop. While some nematodes were isolated from decaying banana roots, Cobb (1893) gave no indication as to whether they were having a significant impact on plant health. The observed disease symptoms in the banana plants were later determined to be caused by banana bunchy top virus (Magee 1927) rather than nematode damage.

Radopholus similis was still a serious pest problem in bananas in Fiji in the 1960s, although damage was variable depending on the banana cultivars grown (Taylor 1969a). Faced with trade barriers, shipping problems and the resulting loss of export markets, the Fiji banana industry experienced a period of decline in the 1950s. Land previously used for growing bananas in the Sawani and Waimbau districts of Viti Levu was planted with ginger (Vilsoni *et al.* 1976), which offered better commercial prospects in the major North American market.

Ginger wilt symptoms and rotting rhizomes were first reported in the 1969-70 season, the cause of which was identified as *Radopholus similis* in 1974. The nematodes in ginger almost certainly originated from the previous banana production. A pathogenicity experiment by Vilsoni *et al*. (1976) demonstrated that *Radopholus similis* isolates from banana were capable of infecting and reproducing on ginger. A 1975 survey estimated *Radopholus similis* to be present in less than ten per cent of Fiji's ginger crop, although in some fields infestation was more than 50 per cent, resulting in yield reductions of almost 40 per cent (Vilsoni *et al*. 1976). A survey of areas adjacent to ginger plots also found *Radopholus similis* in a number of other plant hosts that are commonly grown amongst, or in rotation with, ginger (Vilsoni *et al*. 1976). A subsequent survey found low numbers of *Radopholus similis* in ginger, taro, yams, bele (island cabbage) and kava (Orton Williams 1980).

Within the Fiji Islands, surveys have found *Radopholus similis* on the islands of Viti Levu, Vanua Levu, Beqa and Koro (Orton Wiliams 1980). Fiji's commercial ginger production is predominantly located on Viti Levu. A 2007 survey of 22 ginger farms across Fiji's nine ginger growing regions found *Radopholus similis* in only two districts, on six farms at Veikoba and Muanaweni (Turaganivalu *et al*. 2013).

Host records for *Radopholus similis* in Fiji are listed in Table 3. Orton Williams (1980) noted that very few of the plant hosts identified in greenhouse pot experiments by Butler and Vilsoni

(1975) and Vilsoni *et al*. (1976) were found infected in the field in a subsequent survey. Taylor (1969b) also reported being unable to find *Radopholus similis* in plant hosts other than banana in Fiji. Therefore, the following host list may not be indicative of the true host status in Fiji.

Table 3 Host records for *Radopholus similis* in Fiji

Scientific name	Common name	Source
Abelmoschus esculentus	okra	Butler and Vilsoni (1975)
Abelmoschus manihot	bele, island cabbage	Butler and Vilsoni (1975)
Alpinia purpurata	red ginger	Butler and Vilsoni (1975)
Arachis hypogaea	peanut	Butler and Vilsoni (1975)
Axonopus compressus	broad leafed carpet grass	Butler and Vilsoni (1975)
Colocasia esculenta	dalo, taro	Vilsoni *et al.* (1976)
Crassocephalum crepidoides	thickhead	Turaganivalu *et al*. (2013)
Curcuma longa	turmeric	Vilsoni *et al*. (1976)
Cyathea sp.	tree fern	Orton Williams (1980)
Dioscorea alata	yam	Butler and Vilsoni (1975)
Dioscorea esculenta	lesser yam	Orton Williams (1980)
Eleusine indica	crowsfoot	Turaganivalu *et al*. (2013)
Hedychium coronarium	white ginger	Orton Williams (1980)
Hedychium flavescens	yellow ginger	Orton Williams (1980)
Heliconia humilis	lobster claw	Vilsoni *et al*. (1976)
Miscanthus floridulus	island reed-grass	Orton Williams (1980)
Musa sapientum	banana	Taylor (1969a)
Pinus caribaea	Caribbean pine	Orton Williams (1980)
Pinus elliottii	slash pine	Orton Williams (1980)
Piper aduncum	spiked pepper	Orton Williams (1980)
Piper methysticum	kava	Butler and Vilsoni (1975)
Pometia pinnata	Fijian longan, dawa	Orton Williams (1980)
Psidium guajava	guava	Orton Williams (1980)
Saccharum edule	Fiji asparagus, duruka	Orton Williams (1980)
Saccharum officinarum	sugarcane	Butler and Vilsoni (1975)
Swietenia macrophylla	mahogany	Orton Williams (1980)
Syzygium malaccense	Malay apple	Orton Williams (1980)
Vigna sinensis	cowpea	Butler and Vilsoni (1975)
Vigna unguiculata	cowpea	Vilsoni *et al*. (1976)
Zea mays	sweet corn	Vilsoni *et al*. (1976)
Zingiber officinale	ginger	Butler and Vilsoni (1975)

Radopholus similis in Australia

The first introductions of *Radopholus similis* into Australia are also uncertain. *Radopholus similis*, described only as *Tylenchus* sp. at the time, was first identified during an investigation into reports of unhealthy banana plants near Cairns in 1917(Illingworth 1920). The importation of infested banana suckers from Fiji sometime between 1860 and 1910 is postulated as the most likely avenue for the introduction of *Radopholus similis* into Australia (Blake 1961; Stirling and Pattison 2008; Tan *et al*. 2010).

Fiji was commonly cited as a source of tropical planting materials for the Australian colonies in the 1800s, but there are also a number of references to plants, including known *Radopholus similis* hosts, being imported from Sourabaya in Dutch East India (Java, Indonesia). Dwarf Cavendish bananas grown in northern NSW were at one time even referred to as Sourabaya bananas (*Clarence & Richmond Examiner* 21 October 1890 p 2), acknowledging their origin. *Radopholus similis* is probably native to the Indo-Malayan region (Marin *et al*. 1998), although it was not formally identified on Java until 1898 (Cramer 1957).

Edgar (1885) reported sourcing banana suckers from Singapore, Java and Fiji for planting in Queensland, and that these particular varieties imported were already present in the colony. In 1892, it was reported that 350 banana plants and 50 pineapple suckers had been imported from Fiji for planting in Coffs Harbour, NSW (*Clarence & Richmond Examiner* 30 August 1892 p 5).

Today *Radopholus similis* remains a pest of bananas in Australia, causing significant losses to the industry (Stirling and Pattison 2008). It is not known as a major pest of other crop plants in Australia, but a number of other hosts have been reported in the literature including sugarcane (Williams (1969), pineapple, tomato, corn, pigeon pea, lablab and sugar-apple (Macleod *et al*. 1994). It is not clear which of these host records, if any, were determined experimentally. Host records for *Radopholus similis* in Australia are listed in Table 4.

Table 4 Host records for *Radopholus similis* in Australia

Scientific name	Common name	Source
Ananas comosus	pineapple	McLeod *et al*. (1994)
Annona squamosa	sugar apple, sweetsop	McLeod *et al*. (1994)
Cajanus cajan	pigeon pea	McLeod *et al*. (1994)
Carpobrotus sp.	pigface	McLeod *et al*. (1994)
Centrosema pubescens	centro	McLeod *et al*. (1994)
Desmodium scorpiurus	tick trefoil	McLeod *et al*. (1994)
Desmodium uncinatum	silverleaf desmodium	McLeod *et al*. (1994)
Lablab purpureus	hyacinth bean	McLeod *et al*. (1994)
Lycopersicon esculentum	tomato	McLeod *et al*. (1994)
Musa acuminata	banana	Colbran (1955)
Musa banksii	native banana	Colbran (1955)
Musa velutina	pink banana	McLeod *et al*. (1994)
Pennisetum clandestinum	kikuyu grass	McLeod *et al.* (1994)
Saccharum officinarum	sugarcane	Williams (1969, Blake (1961)

Sorghum sudanense	sudangrass	McLeod *et al.* (1994)
Mucuna (*Stizolobium*) sp.	velvet bean	McLeod *et al*. (1994)
Stylosanthes humilis	Townsville stylo	McLeod *et al*. (1994)
Vigna marina	dune bean	McLeod *et al*. (1994)
Vigna mungo	mung bean	McLeod *et al*. (1994)
Zea mays	sweet corn	McLeod *et al*. (1994)

There are no published records of *Radopholus similis* on ginger from Australia. However, *Radopholus similis* has been found at least once in ginger on a farm near Eumundi, Queensland, in the mid 1990s. The population was reported to be relatively low, and not causing noticeable symptoms on the plants. A follow-up test in the glasshouse confirmed that the nematode did not multiply readily on ginger (Stirling 2014).

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Appendix 3 Ginger production in Fiji

Typical ginger production practices in Fiji

Site selection and land preparation

In Fiji, ginger is commonly grown on small farms, mostly of less than one hectare in size (Turaganivalu *et al*. 2013) (Figure 2), although there are some larger farms (Figure 3). Ginger is susceptible to rhizome rot if the soil is too wet (Ministry of Agriculture 2013), so there is a preference to farm on hilly land, as the heavy wet season rainfall can result in waterlogged soil in low lying areas. However, farming steeply sloped land creates problems of erosion and nutrient leaching (Buresova and McGregor 1990). Planting on slopes of less than 15 degrees is recommended to reduce erosion (Ministry of Agriculture 2013). Newly cleared virgin land may be used if available, but ginger is commonly grown on land previously cropped with cassava or taro, or on fallow land.

Figure 2 Typical small ginger farm, Naqati Settlement, Vugalei

Ginger is planted in rotation with other crops that are poor *Radopholus similis* hosts. Typical crop rotation involves ginger, taro, cassava and a fallow period prior to planting ginger again. Alternatively, some growers may plant leafy vegetables, velvet bean, watermelon, sweet potato and duruka (Fijian asparagus) in a crop rotation schedule.

Figure 3 Ginger farm, Naboro, Suva

The block is sub-divided into plots (Figure 4), and the soil is cleared of volunteer plants from the previous crop, as well as any weeds. Herbicides may be used to control weeds prior to planting. Two common weeds, crowsfoot (*Eluesine indica*) and thick head (*Crassocephalum crepidoides*) are able to host *Radopholus similis* (Turaganivalu *et al*. 2013) so should be removed. Land preparation is usually done manually, but a few growers have introduced mechanized diggers.

Figure 4 – Block subdivided into plots prior to planting, Naboro, Suva

Poultry manure is applied to the soil in preparation for planting, at around ten tonnes per hectare. The soil is turned with a digging fork to mix in the manure. The soil may be left for a few weeks to allow the manure to decompose before turning again to ensure the soil is fine and loose (McGregor 1988). Some growers may also add a NPK (nitrogen, phosphorus, potassium) fertilizer at planting time (Ministry of Agriculture 2013).

Seed selection and planting

Seed treatment is recommended to ensure planting materials are free of pests and diseases. Seed rhizomes should not have any damaged eyes or signs of rot. The rhizomes are cut into 60 to 70 gram pieces that each have at least two eyes (Ministry of Agriculture 2013). In Fiji, seed rhizomes are typically allowed to air dry under shade for eight to ten days (Smith *et al*. 2012) to allow cuts to heal before planting (Ministry of Agriculture 2013).

Seed rhizomes should be treated soon after harvest, prior to sprouting. Later treatment can result in poor germination and stunting of plant growth. Hot water treatment is commonly practised by most growers in Fiji. The government has provided gas facilities for hot water treatment of planting material, including loaning a small gas-fired vat to growers. Some growers have used sun drying as an alternative seed treatment, while dipping in fungicide (Tricho-Shield) is also sometimes used.

Crop management

Land preparation prior to planting should aim to remove most weeds. Herbicides, such as Atrazine, may be applied soon after planting to prevent competition for nutrients, water and light after the new crop emerges. Subsequent weeding is done manually by labourers as the crop grows.

Once the ginger shoots are at the two to three leaf stage, hilling is undertaken to raise the level of soil around the plants. Urea is also applied at this time, around 100 kilograms per hectare (Ministry of Agriculture 2013). A second hilling and application of urea is done eight weeks later, with a third hilling and addition of urea usually done four weeks after that. Additional urea may be applied later to crops being grown for mature harvest.

Harvesting

Immature ginger is typically harvested after five months, usually at around 24 to 26 weeks from planting. The time of harvest is determined by the fibre content, which increases with maturity. A fibre content of no more than 40 per cent is recommended for ginger harvested for processing. Immature ginger is usually harvested in February and March (Ministry of Agriculture 2013). Mature ginger is harvested after around nine or ten months, and is harvested from July to October.

Rhizomes are harvested manually with a digging fork, and the tops trimmed in the field. Excess soil is removed prior to bagging or placing in crates.

Postharvest handling

After harvest, ginger is transferred to the packhouse for washing, trimming, curing, grading and packing. An initial grading and quality control check is undertaken to remove rhizomes unsuitable for export. Rhizomes are placed on wire racks for washing to allow sufficient

drainage. All soil is removed, as well as roots and shoots, taking care not to damage the skin. The washed ginger is then transferred to clean drying racks for curing. The ginger is spread thinly on the racks, which are layered to facilitate air movement.

The ginger is then cured in a sheltered area with good air circulation for five to ten days. This process allows any cuts to heal, which reduces the incidence of spoilage due to postharvest pathogens. The rhizomes are then graded and prepared for export, with any remaining roots removed, and any rhizomes with excessive cuts or bruises, disease symptoms (soft rot), insect damage or sunburn are culled. The ginger is packed in cardboard boxes for export. The ginger is stored in a clean area, segregated from non-export product, and free from insects and other contaminants.

The ginger export pathway in Fiji

Growing ginger for export to Australia

All fresh ginger exported to Australia must be sourced from registered blocks to ensure the ginger has been produced and harvested in accordance with standard commercial production practices (as presented in the Technical Bulletin, see Figure 5 below). Registration also facilitates product trace-back should issues be identified with non-conforming imports in Australia. Ginger growers must apply for registration with the Ministry of Agriculture no later than eight weeks prior to harvest. Records detailing the field activities for each block during the season must be maintained by the grower. In addition to Australia's import requirements, Fiji is undertaking soil testing for nematodes prior to granting export approval to growers, with approval contingent on an absence of *Radopholus similis* in the samples (Ministry of Agriculture 2015).

All ginger intended for export to Australia must be prepared and packed in registered facilities. This is to ensure the ginger has been packed in accordance with standard commercial packing practices. Only ginger sourced from registered growers can be packed for export. In most cases the packhouse is also the exporter. The packhouse must have a documented system to identify and segregate ginger from different growers, and processes to remove all soil contamination. Records of staff training, hygiene processes, and ginger throughput for each grower for every consignment must be maintained.

Any fumigation treatment performed prior to export must be done at a registered facility by a treatment operator approved by the Biosecurity Authority of Fiji. Exporters must ensure the product meets Australia's quarantine standard, and packaging and labelling requirements. A one hundred per cent grower line inspection of the ginger must be conducted by the quality controller prior to presenting the consignment for phytosanitary inspection and certification by the Biosecurity Authority of Fiji.

Figure 5 Technical Bulletin: Ginger production in Fiji

TECHNICAL BULLETIN

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GINGER PRODUCTION IN FIJI

A healthy ginger plant

GINGER is currently grown in the Central Division, concentrated mainly in the provinces of Naitaisiri, Tailevu, Serua and Namosi.

Soil Requirements

Ginger adapts well to a variety of soils ranging from peat to light clays, but performs best on light-textured soils.
Soil should be loose and friable so that little resistance is encountered as the rhizomes develop. A friable loam, rich in humus is ideal for ginger. It is important that the soils are well drained to avoid rhizome rot.

Climatic Requirements

Ginger thrives in a hot moist climate particularly during the early rapid growth phase. Annual rainfall in excess of 3,000mm accompanied by a prolonged hot season is preferred. Ginger also requires a long hot period for the development and maturity of rhizomes.

Cropping Season

- Ginger is a seasonal crop.
- Land preparation begins in July/August followed by planting in September to November before the onset of the wet season.
- Planting of immature ginger is usually completed by the end of September and the crop is harvested 5 months later in February.
- Mature ginger takes 9-10 months to mature and is harvested from July-October.

Recommended Varieties

- White ginger [Canton]
- Red ginger

Expected Yield

- Immature is 20 – 25tonnes/ha
- Mature is 25 – 30tonnes/ha

Seed Rate

- Immature – 7.5tonnes/ha
- Mature – 5tonnes/ha

Seed Spacing

- Immature - 60cm x 15cm and Mature – 60cm x 20cm on slope
- Immature – 90cm x 15cm and Mature – 90cm x 20 cm on flat land & semi-mechanized

Seed Selection

- Select seeds only from healthy plants
- Seeds should not have any damaged eyes, rotten edges or thick swelling
- Seeds should be free from diseases
- Cut rhizomes into pieces that have two eyes or more and weigh approximately 60–70 grams
- Allow cut to heal before seed treatment to protect from excessive heat injury.

Seed Treatment

Seed treatment is highly recommended for the control of nematodes and *Pythium* rots in order to attain pest-free (CLEAN) planting material.

Plant healthy seeds only

A. Hot-Water Treatment

1. Place the tank on level ground in a shaded area.
2. Fill the tank with water to about 15cm (6") from the top.
3. Heat the water (using a gas burner) to 51°C. Adjust the burner to maintain this temperature.
4. Fill the first bag with ginger seed, and immerse it on the right hand side of the tank (facing the burner). Adjust (increase) burner to bring temperature back to 51°C and maintain. (Temperature usually drops when bags of ginger are put into the tank).
5. Begin timing when temperature reaches 51°C.
6. Keep bags submerged for 10 minutes then remove.

B. Fungicide Treatment (following hot water treatment)

This treatment is for the control of rhizome rot caused by *Pythium* spp.

1. Following the hot water treatment, shake off excess water until dripping stops.
2. Prepare a fungicide solution (3.5g Sundomil in 1 Litre of water). If using a 200L drum, half fill drum to (100L) and add 350g fungicide to make a solution. Mix well.
3. Dip bags into the fungicide solution and remove after 5 minutes.
4. Distribute seeds onto a clean hard surface and spread into a single layer to cool.
5. After 4–5 days, reject seed pieces that show shriveling or off-colour. Good seeds should be firm and shiny.

Seeds should be treated soon after harvest, sometime in August to the end of September. During this time the seeds are dormant.

Seeds should not be treated when they are sprouting (usually in October/November); this could result in poor germination and increased stunting of plants.

Site Selection

- Avoid excessively steep slopes.
- Plant only on slopes that are less than 15° to reduce soil erosion.
- Do not plant on wet land or poorly drained land to avoid rot and wilting.

Crop Rotation

- Use a 4 year rotation of ginger – dalo – cassava –fallow–ginger on previously farmed land.
- Do not select sites previously planted with ginger, bele, yams, bananas or tomatoes.
- Alternatively, use newly cleared land to minimise pest & disease problems.

Land Preparation

Use appropriate soil conservation measures on slopes;

- Run drains across slopes
- Weed and clear land in the month of May
- First digging and application of poultry manure to the soil in the month of July
- The second digging is in late August. Again, work in poultry manure until soil is fine and loose

Fertilizer

- Poultry manure – 10t/ha (400kg/sq. chain) applied at the first digging
- NPK: 13:13:21 at 1t/ha [40kg/square chain] – apply as split application of 500kg/ha (20kg/ square chain) at planting and a second application of 500kg/ha (20kg/ square chain) 3 months after planting.
- Urea application of 300kg/ha [12.0kg/sq. chain] at 3 applications for Immature ginger. First 100kg/ha application at 2–3 leaf stages, second 100kg/ha application 8 weeks after the 1st application and third 100kg/ha application at 4 weeks after the 2nd application.
- For mature ginger urea application can be spread over for a 4th application in February.

Hilling

This is done simultaneously with the applications of urea.

- First hilling at the 2–3 leaf stages, then 8 weeks after 1st hilling and 4 weeks after 2nd hilling.
- Do not hill in wet conditions.
- Care should be taken during hilling not to damage roots and rhizomes as the crop can be infected with diseases through the damaged roots.

Time of Maturity

- Immature ginger – 5 months (24–26 weeks after planting) in March
- Mature ginger – 10 months after planting in July

Harvesting and Storage

- Immature ginger is generally harvested after 5 months (24–26 weeks) from planting. If harvested too early, yields will be low. If harvested too late, the fiber content is likely to exceed the recommended level of 40% or below. The optimal time of harvest can be confirmed by tests carried out by Extension Officers.
- Mature ginger is generally harvested 10 months after planting.

Pest Management

1. Weed Control

Weeds compete with ginger for nutrients, water and light resulting in slow growth of the ginger plant and smaller rhizome development. For example, the nuts/rhizomes of nutgrass and sedge can penetrate the ginger rhizome resulting in low yield and creating entry for pathogens or disease-causing organisms. If proper weed control is done before planting there should be fewer weeds after planting.

Keep fields free of weeds

One way of preventing weeds is through good land preparation. However, soon after planting apply Atrazine as a pre-emergence weed control at a rate of 56g in 14L of water. If applied at the right time and to the right amount this should keep weeds under control for about 8 weeks. After this, undertake manual weeding or by weed wiper, if need arises.

2. Disease Control

2.1 Rhizome Rot

Rhizome rot occurs during wet and warm weather conditions and where there is poor drainage.

In mature plants, disease infection occurs in the rhizome and collar region of the plant with yellowing of leaves and collapse of affected shoots as the above-ground symptoms. Below ground level, the shoot collapses and water-soaked lesions appear on the rhizome and it rots quickly. Three *Pythium* species have been identified in Fiji to cause this rhizome rot; *Pythium myriotylum, P. vexans, P. graminicola* (Lomavatu *et al 2010)*. In some instances this fungus can cause severe crop loss.

Yellowing of leaves caused by *Pythium* spp.

Management of Rhizome Rot

1. Use ONLY clean planting seed material and prevent transferring or moving soil from known infected areas.
2. Improve drainage and improve water infiltration rates of soil. This is to prevent soil becoming saturated. This should also slow the disease spread.
3. Remove all volunteer ginger plants from rotation crops to reduce the level of this fungus in the soil.
4. Once a diseased plant appears, carefully remove the plant and the surrounding soil, and put in a bag, so that infected soil does not contaminate the field. Apply a fungicide to plants and surrounding areas.
5. Improve soil health since *Pythium* thrives in soil with low biological activity. This can be done by integrating or adding organic amendments such as compost, plant material and wood chips/ saw dust into the soil.

2.2 Burrowing Nematode

Radopholus similis, a burrowing nematode, is the most destructive of nematodes present in Fiji and can cause significant losses to mature ginger and seed ginger. The burrowing nematode is spread primarily on infested seed ginger but also in soil. In the field, the nematode population survives on volunteer ginger and also on common weeds such as Crows Foot (*Eleusine indica* (L.) (Gaertn), and sometimes on cassava.

Management of Burrowing Nematode

1. Use only "CLEAN" seed material for planting and prevent heavily infested soil from being transferred off-site.
2. Seeds should be hot water treated before planting (see *Seed treatment* above).
3. Reduce nematode levels in soil by:
   - i. Remove volunteer ginger from rotation crops
   - ii. Practice crop rotation (ginger – dalo – cassava – 1-2 years of fallow – ginger)
   - iii. Control weeds

4. The initial application of poultry manure during land preparation is crucial for the control of Burrowing nematode (refer to *Land Preparation*)
5. Crop husbandry

All practices which promote optimum growth of the ginger plant will aid the crop in overcoming the effects of nematode and other pest infestation. Ensure that the recommendations are followed for:

i. Weed control
ii. Insect pest control
iii. Disease control
iv. Proper drainage
v. Fertilizer application

Ginger rhizome showing Nematode damage

Harvesting

Carefully dig up rhizomes to avoid damage and breakage of rhizomes and trim off tops.

Avoid walking on un-harvested ridges in the field as this causes unnecessary breakage. Remove excess soil from ginger before bagging or loading in crates. Properly stack crates in preparation for transfer to cleaning facility (packhouse).

Storage Requirements

- Optimal storage conditions: 13°C
- Relative humidity: 65%
- Chilling injury: <13°C

Ginger is susceptible to chilling injury that intensifies shriveling and increases the incidence of decay.

Postharvest Handling

Proper postharvest handling is essential for maintaining good quality ginger rhizomes.

Pre-Conditioning

- Washing of rhizomes is required to remove all soil, therefore water pressure should be sufficient to remove soil but not damage the rhizome skin. Ideally, washing should be done on racks that allow ample of drainage.
- Use only clean water, as recycled water may spread diseases.
- Keep the washing area clean of decayed or rejected ginger.
- Place washed ginger on clean drying racks to be cured.

Curing

- Place racks with cleaned and washed ginger in an area sheltered from rain and with good air circulation.
- To facilitate air movement, it is important to have ginger rhizomes layered thinly on racks.
- Curing between 5 to 10 days to properly heal cuts and small bruises.

Grading Standards

- Rhizomes should be dry, clean, firm and of good colour
- Maintain similar varietal characteristics, i.e. ginger rhizomes that have the same fiber content, colour and flavor
- Graded into similar sizes
- Rhizomes must be free from soil, seeds, decay and insect pests
- Discard rhizomes with:
  i) excessive cuts and bruises
  ii) soft rot (meaning soft mushy conditions of tissue)
  iii) worm holes
  iv) sunburn
- Colour: a silvery tan colour should cover more than ½ of rhizome at time of harvest.
- Texture: crisp, firm, with little fiber in the flesh. No shriveling or soft tissue.

Ginger for Export

If you would like to export ginger, please contact your Extension Officer and/or Biosecurity Authority of Fiji (BAF) to obtain the latest requirements by ginger importing countries.

Reference:

1. Ginger Production in Fiji (2011) Technical Bulletin Ministry of Primary Industries.

2. Lomavatu MF, Conway J, Aiken E (2009) Molecular identification of Pythium isolates of ginger from Fiji and Australia. APPS Conference Newcastle, September 2009.

Source: Fiji Ministry of Agriculture 2013

Appendix 4 Stakeholder consultation

Technical experts' panel teleconference

A teleconference was held on 20 January 2015 to discuss the review process and research on *Radopholus similis*. Participants included the experts nominated by stakeholder groups, Dr Mike Smith and Jennifer Cobon from QDAF, and Dr Visoni Timote from BAF. A number of other officials from QDAF, BAF, and MoA also took part.

To comply with *Privacy Act 1988* requirements, some names and other personal information have been removed from these teleconference minutes.

Teleconference minutes

Date: 20 January 2015

Time: 10:00 am (AEDST)

Chair: Ms Lois Ransom

Chair: Ms Ransom informed that she would act as Chair in Dr Ritman's absence.

Welcomed and thanked participants for their involvement, and indicated that these discussions will be taken into account to inform the review.

Requested participants introduce themselves.

Introduced the agenda, noted that discussions were being recorded for minuting purposes, discussed the Terms of Reference (ToR) for the review, potential conflict of interest, confidentiality, and indicated that the Technical Expert Panel (TEP) focus on:

1) the quarantine status of *Radopholus similis*
2) phytosanitary measures (conditional upon the outcome of 1)

TEP: Agreed the focus/priority of work and indicated no objections to recording.

Chair: ToR and Declaration of Interest documents will be circulated to TEP.

QDAF: Informed that they were undertaking a repeat of the Australian *Radopholus similis* pathogenicity experiment, using the same methodology to Cobon *et al.* 2012, with inoculation probably occurring this week. They indicated that they are prepared to share this data.

Chair: Opened discussion on the 'ideal' experimental design required to inform the unresolved question of the quarantine status of *Radopholus similis*, should it be required for future consideration.

QDAF: Proposed the need for further robust research where a representative range of Fijian/Australian *Radopholus similis* isolates could be compared for pathogenicity and genetic differences, within and between populations, in tandem and under the same conditions.

Fiji: Agreed that appropriately designed experiments may be required to resolve the issue.

Chair: Explained the context to the provisional quarantine status of *Radopholus similis*, Australia's obligations under SPS Agreement and the need for scientific justification for measures.

Chair: Asked the TEP what the perceived gaps in our current knowledge are, and how they could be filled.

DA: Presented an overview of the current status of the scientific literature review, which has provisionally focused on themes, including: genetic variation, host preference, pathogenicity, behaviour and optimal environmental conditions. Asked for further information on key identified gaps in knowledge including:

- Genetic variation – not much published research examining Fijian isolates, some information on Australian isolates on banana. Is there more complete information available? Do we need to undertake specific research on this?
- Host preference – are there additional Fijian/Australian host records or information?
- Pathogenicity – not much research has been done on ginger. Further information on impacts on banana in subtropical Australia may be useful. Any information about pathogenicity on other hosts in Fiji.
- Survival requirements and climate preferences – response of *Radopholus similis* to lower temperatures; differences between tropical and subtropical populations.

QDAF: Indicated the global host range of *Radopholus similis* is broad, but Australia's *Radopholus similis* distribution is associated with areas of banana production, so data was therefore limited on other potential Australian hosts. However, it was noted that *Radopholus similis* has not been observed on ginger growing near banana production within Australia. All *Radopholus similis* isolates examined so far could be inoculated onto banana, although there is observed variability between Australian isolates in banana. There is no direct comparison between Fijian and Australian isolates. It is speculated that there could be a difference in virulence or host preference, rather than some other factor.

Fiji: Banana is not usually planted after ginger in Fiji. Commercial banana production has declined in Fiji, being replaced by ginger. More resistant banana varieties are now being planted, and Cavendish varieties no longer grown. Therefore, *Radopholus similis* exposure to banana is now limited in Fiji.

QDAF: All cultivars of banana tested in Australia are susceptible to *Radopholus similis*.

QDAF: There does seem to be genetic diversity amongst *Radopholus similis* populations in different geographical regions. The literature doesn't make direct comparisons between Fiji and Australian isolates. Also, in the available studies only small samples are typically used, so it's not a good population study for looking at pathogenicity or virulence or host range differences. There is not a lot of good information to make that comparison.

Chair: Asked about evidence for acquired pathogenicity or differential pathogenicity in *Radopholus similis.*

QDAF: Some work has looked at pathogenicity genes in different populations, and some differences have been shown, but this hasn't been followed up. In the citrus strain it is unclear if pathogenicity is genetic or behavioural, and the scientific community is divided. There is also a lack of knowledge on the comparative variation in Australian and Fijian populations.

Fiji: Population increase is the primary factor that impacts pathogenicity. Without crop rotation *Radopholus similis* numbers increase on ginger and there is greater pathogenicity compared with rotating with taro and cassava.

Chair: Asked what level of genetic difference is sufficient to support a claim for strain differences.

QDAF: There is global variation, but no relevant comparison between Fijian and Australian isolates. Suggested experiments as outlined above would be required. Tan *et al.* 2010 had investigated genetic variation in the Australian *Radopholus similis* population. There is not enough known about variability in Fiji's *Radopholus similis* population.

Chair: Asked what type of robust method would be required to investigate genetic diversity.

QDAF: If you did molecular analysis, either RAPD, AFLP or gene sequencing, in tandem with pathogenicity tests in Australian and Fiji using the same isolates under the same experimental conditions, you would be reasonably well informed about differences between the strains, as long as you had representative populations with enough isolates to compare.

Chair: Asked what part of the genome would be useful to study the level of genetic variation?

QDAF: Most of the literature has looked at either ITS or IGS sequencing, RAPD or AFLP analysis, so would need to look at literature to see what regions would be most informative.

Fiji: Agreed that tandem pathogenicity and molecular studies would be required, provided pathogenicity tests were carried out properly.

Chair: Asked about the different *Radopholus similis* isolates you would need to select.

QDAF: Isolates from ginger (including wild-ginger) and other crops in Fiji; in Australia isolates could be selected geographically from different climatic zones. Tan *et al*. has done this previously and found no genetic variation, but QDAF has done pathogenicity tests and found different isolates sometimes behave differently on the same banana cultivar. Would need to compare effects on both ginger and banana with isolates from both countries, but do it in a manageable way in terms of space required, and under strict quarantine requirements.

Chair: Asked about the management of *Radopholus similis* during Fijian ginger production.

QDAF: A survey of *Radopholus similis* in production areas is needed to understand geographical distribution and level of infestation.

Fiji: Responded that Fiji had preliminary survey data indicating absence of *Radopholus similis* from ginger and banana in commercial ginger production areas, including previously infested farms. Intensive surveys have been done on farms in Veikoba and Muaniweni, but no *Radopholus similis* were found. During the surveys other nematodes were found, including *Meloidogyne* and

reniform nematodes. Fiji indicated that the survey is not complete, but they are prepared to share the survey data.

Fiji: Previous infestations of *Radopholus similis* in ginger were the result of not practicing the hot water treatment recommended by the Ministry of Agriculture. Now agricultural extension officers are monitoring proper seed rhizome hot water treatment prior to planting. Also, the practice of rotation with non-host crops (for example taro, cassava), or not replanting ginger without a fallow period of two years has most likely contributed to *Radopholus similis* not being found. Few farmers replant on the same land each year.

Fiji: No *Radopholus similis*, alive or dead, have been found in ginger exported to Australia.

Chair: Requested TEP to share any additional pertinent information (noting the list of key publications previously circulated), and/or suggest further experts DA could consult.

QDAF: Suggested follow up with [name redacted] and [name redacted] (for *Radopholus similis* in banana).

Fiji: Suggested follow up with [name redacted] and [name redacted].

Chair: Asked if there were any additional issues. None were raised.

Next steps/actions:

DA: To continue analysis of the scientific literature, writing the draft report and identifying areas for further action/discussion with the TEP; to circulate ToR and Declaration of Interest documents and minutes of this meeting to the TEP; and to have follow up discussions with individual TEP members, as required.

TEP: To share any additional pertinent data.

TEP: To participate in next teleconference (TBA).

Meeting summary – Brisbane meeting with QDAF

A technical meeting was held with QDAF and AGIA in Brisbane on 3 March to discuss *Radopholus similis* pathogenicity and observe a pathogenicity experiment being conducted at the QDAF facility. Participants included the experts nominated by AGIA and QDAF, Dr Mike Smith and Jennifer Cobon from QDAF.

Technical discussion on *Radopholus similis* at QDAF, Ecosciences Precinct, Brisbane

QDAF researchers, DA officers and an AGIA representative undertook discussions on past, current and potential future research of relevance to *Radopholus similis* pathogenicity. This included:

- QDAF researchers provided clarification of the experimental design used in Cobon *et al.* (2012), and discussed the results and conclusions reached.
- QDAF's intent to undertake an experiment to compare Fijian and Australian *Radopholus similis* isolates side-by-side in an appropriately controlled experiment to further investigate the quarantine status of *Radopholus similis* was discussed. It was agreed that such an experiment would be the best, and probably, only way to establish whether Australian and Fijian isolates had significantly different pathogenicity on ginger.
- It was agreed that experimental design would need to include consideration of appropriate controls to accommodate the apparent high level of biological pot-to-pot variation in factors used to measure pathogenicity and the need to be timed to avoid plant senescence under Australian conditions.
- QDAF also suggested it would be useful to undertake molecular testing and comparison of the Australian and Fijian isolates of *Radopholus similis* for any sign of variation.
- QDAF indicated this experiment could commence in September 2015, in Australia, subject to Fijian *Radopholus similis* being available.
- The intent is to agree on the methodology before any experiment is conducted. This would include agreement by Fiji.
- QDAF indicated they could conduct the experiment in Australia under appropriate quarantine containment, as they have access to quarantine approved laboratory and glasshouse space.
- In order for this to occur, QDAF would require Fijian *Radopholus similis* cultures for (i) molecular testing and (ii) pathogenicity testing, within Australia. It was agreed that the DA would enquire about:
  - What Fijian isolates/cultures (live/dead) are potentially available from any host?
  - If there were any Fijian cultures derived from banana and/or could such a sample be acquired from banana?
  - If Fiji is willing to provide cultures and/or samples for the proposed purposes?
  - What molecular work has been completed on Fijian *Radopholus similis* and/or what capacity is there to undertake further work, if required?
- QDAF advised that their attempt to replicate the original experiment conducted by Cobon *et al.* (2012) had commenced. There was discussion on experimental detail and DA viewed the

experiment in the glasshouse (inoculated on 21 January). Unfortunately, the experiment has been compromised by *Fusarium* wilt introduced via infected seed-rhizome and consequent senescence. Plant growth may also have been affected by significant hail damage to the glasshouse and its shading.

- DA indicated its intent to follow up with the Fijian authorities on the results on the results of their nematode survey data. This important piece of additional information would be taken into consideration in the review. DA also agreed to follow up specific questions on the Fijian survey methodology, including:
  - What was the survey coverage relative to ginger production areas?
  - Were samples taken from roots and soil?
  - Were sample taken late and/or early harvests?
  - Did sampling coincide with ginger exports?
  - Did the survey also test other hosts in ginger fields (for example, crowsfoot) or ginger volunteers after harvest?
  - Who conducted the survey and what level of training/experience did surveyors have?
  - What oversight was in place by Fijian authorities?
- Details on Fijian ginger production practices were also discussed. DA agreed to follow up with the Fijians specific questions raised, including:
  - How Fijian growers produce/source ginger seed-rhizomes, what practices were in place for clean seed-rhizome production, and uptake by export growers.
  - What crop rotation practices were in place for the suppression of nematode populations in the field, and uptake by export growers.

Next steps/Actions

DA: To follow up with Fijian authorities:

- The results of the nematode survey data
- Additional questions raised on survey and production practices
- The availability of *Radopholus similis* cultures for (i) molecular testing and (ii) pathogenicity testing.

QDAF: To consider and propose a first draft of experimental methodology for their proposed experiment to compare Fijian and Australian *Radopholus similis* isolates side-by-side, with appropriate controls, for agreement by all parties.

Appendix 5 Summary of Fiji visit 10 to 12 March 2015

Purpose

The purpose of this trip was to gather information for the review of import conditions for fresh ginger from Fiji, which was commenced in November 2014. The visit provided an opportunity to observe ginger production for export to gain a better understanding of crop management, pest and disease issues and regulation of the export pathway.

Entry meeting

Department officials met with the Biosecurity Authority of Fiji (BAF) and Ministry of Agriculture (MoA) at the BAF headquarters in Suva on 10 March.

MoA provided an update on plans for the 2015 export season, and activities of the Ministry's extension officers. The current season has experienced good weather to date, and a good crop is expected. Little yellowing has been observed in the crop indicating few problems with Pythium. The main nematodes are root knot nematodes (*Meloidogyne* spp.) and reniform nematode (*Rotylenchulus reniformis*). Spiral nematodes (*Helicotylenchus* spp.) and ring nematodes (*Criconema* spp.) are found in some areas. No *Radopholus similis* have been found in the ginger crops surveyed.

As of March 2015 there are 14 ginger growers registered for export in the 2015 season. Growers must be registered at least eight weeks prior to harvest so it is expected that more growers will register. Extension officers work closely with the growers to ensure compliance with guidelines contained in the MoA Technical Bulletin. Around 560 farmers have received training in the 16 training sessions run by the Extension Division. The extension officers typically have responsibility for three districts, each with around 15 to 20 villages. Ginger growers are mostly located near Suva in the Central Division, predominantly in the Rewa, Niatisiri and Tailevu provinces.

Most farms are relatively small. The typical Fijian grower usually farms around half to one acre (0.2 to 0.4 hectares). A few Chinese growers have larger farms, around ten to twenty acres (four to eight hectares).

Growers are encouraged to grow their own seed rhizomes for planting, but MoA can provide subsidised seed if necessary. During supply shortages this can cost up to $1.50 FJD per kilogram. A one hectare crop for seed production has been established in the Western Division, away from the main production areas. MoA Extension provides training to growers on preparing and treating their seed. Portable vats owned by the Ministry can be loaned to growers. Recommended treatment is 51 degrees Celsius held for ten minutes once correct temperature has been attained. Soil testing may be conducted prior to planting, at immature harvest, and again if there is a mature harvest. Registration for export is contingent on the results of this testing.

There are presently three registered packhouses approved for the export of fresh ginger: Sai Yee Foods, Kaiming and Ranadi. Amalgamated Pest Control is the only approved provider of fumigation treatments for export of fresh ginger.

A report prepared by the MoA on the work done to enhance and maintain the ginger export pathway was distributed and discussed (Ministry of Agriculture 2015). Crop rotation typically involves taro, cassava and a fallow period. Some growers may also plant leafy vegetables, sweet potato and duruka (Fijian asparagus). Growers have been encouraged to plant in new areas that have not previously been used for ginger production.

Fiji ginger nematode survey work

The nematode survey work was discussed, and a summary presented in a report (Ministry of Agriculture 2015), which is available on the department's website. A total of 55 ginger farms were surveyed in seven localities in 2014, including Muanaweni (June), Navua (July), Waibau, Veikoba, Lomaivuna and Naboro (September). Additional surveys of volunteer ginger, crowsfoot, banana, taro and cassava were carried out in February 2015 in Muanaweni and Veikoba, two areas previously infested with *Radopholus similis*.

Nematode sampling and identification was done by the MoA's Research Division. Soil samples from 55 ginger fields in these localities were collected. Soil samples were collected from other hosts as well, including banana, eggplant and crowsfoot. Some ginger rhizomes were also tested.

Soil sampling involved taking soil 0 to 20 centimetres deep from the rhizosphere of ten plants in each field, then combining subsamples into a single composite sample. Nematode extraction involved spreading 200 millilitres of soil on an extraction tray for 48 hours and then filtering twice through a 38 micrometre sieve.

Extracting nematodes from the rhizome samples involved cutting into 70 gram pieces, placing in 200 millilitres of water and macerating in a blender for ten seconds. The material was then placed on an extraction tray for 24 hours and sieved.

Nematodes were identified using morphological characters by the nematologist at the Koronivia Plant Pathology laboratory. Four genera of nematodes were commonly found in the surveys: *Rotylenchulus reniformis*, *Helicotylenchus* spp., *Criconema* spp. and *Meloidogyne* spp. These same nematodes were also present in the soil samples collected from around banana and eggplant, and the samples from fallow land. No *Radopholus similis* were found in any soil or rhizome samples. Only *Meloidogyne* spp. were extracted from the rhizome samples.

Rotylenchulus reniformis was found in the soil of 41 of the 55 fields surveyed, and was by far the most widely distributed nematode present. *Helicotylenchus* spp. were found in the soil from 23 fields, particularly in the Naboro district. *Criconema* spp. (ring nematodes) were found in 14 fields, while *Meloidogyne* spp. were present in the soil in six fields, mostly in Navua.

Relative nematode population densities between species varied in the samples. *Rotylenchulus reniformis* was the most numerous species in 51 per cent of the samples, *Helicotylenchus* spp. the most common in 28 per cent of samples, *Criconema* spp. in 13 per cent and *Meloidogyne* in ten per cent.

In the past *Radopholus similis* was a problem in some areas. A survey in 2007 found *Radopholus similis* was the dominant nematode on farms in Muanaweni and Veikoba. Sampling from these same fields was undertaken in September 2014, but no *Radopholus similis* were present. Further sampling of volunteer ginger and weeds such as crowsfoot in these fields was done again in February 2015. No *Radopholus similis* were found in any of the samples.

Further research

Fiji indicated they were willing to assist in further experimental research into *Radopholus similis*. However, MoA Research no longer has any live cultures of *Radopholus similis* isolated from either banana or ginger. Cultures previously maintained at the Koronivia Research Station were given to the University of the South Pacific in Suva a few years ago but it is understood these cultures no longer exist. It is likely that if live *Radopholus similis* cultures are needed for further research, the nematodes will need to be collected from the field.

Obtaining *Radopholus similis* isolates from ginger may be difficult, as this species has not been found in ginger in Fiji for a number of years. It may be possible to find *Radopholus similis* in banana but it also is no longer common and has not been identified in samples for some time. Some *Radopholus similis* were isolated from banana roots in the Sigatoka Valley in 2010. Extension officers have not encountered disease in bananas caused by *Radopholus similis* in recent years, and no farmers have reported problems to MoA.

MoA researchers have not done any molecular work to identify possible differences in *Radopholus similis* in Fiji. They are not aware of any published research examining different Fiji isolates. Fiji does not have preserved specimens that could be subject to molecular testing. New specimens will need to be obtained from the field if molecular work is to be undertaken.

Field visits

A number of ginger farms and packhouse facilities were visited, as well as the MoA Koronivia Research Station Plant pathology laboratory.

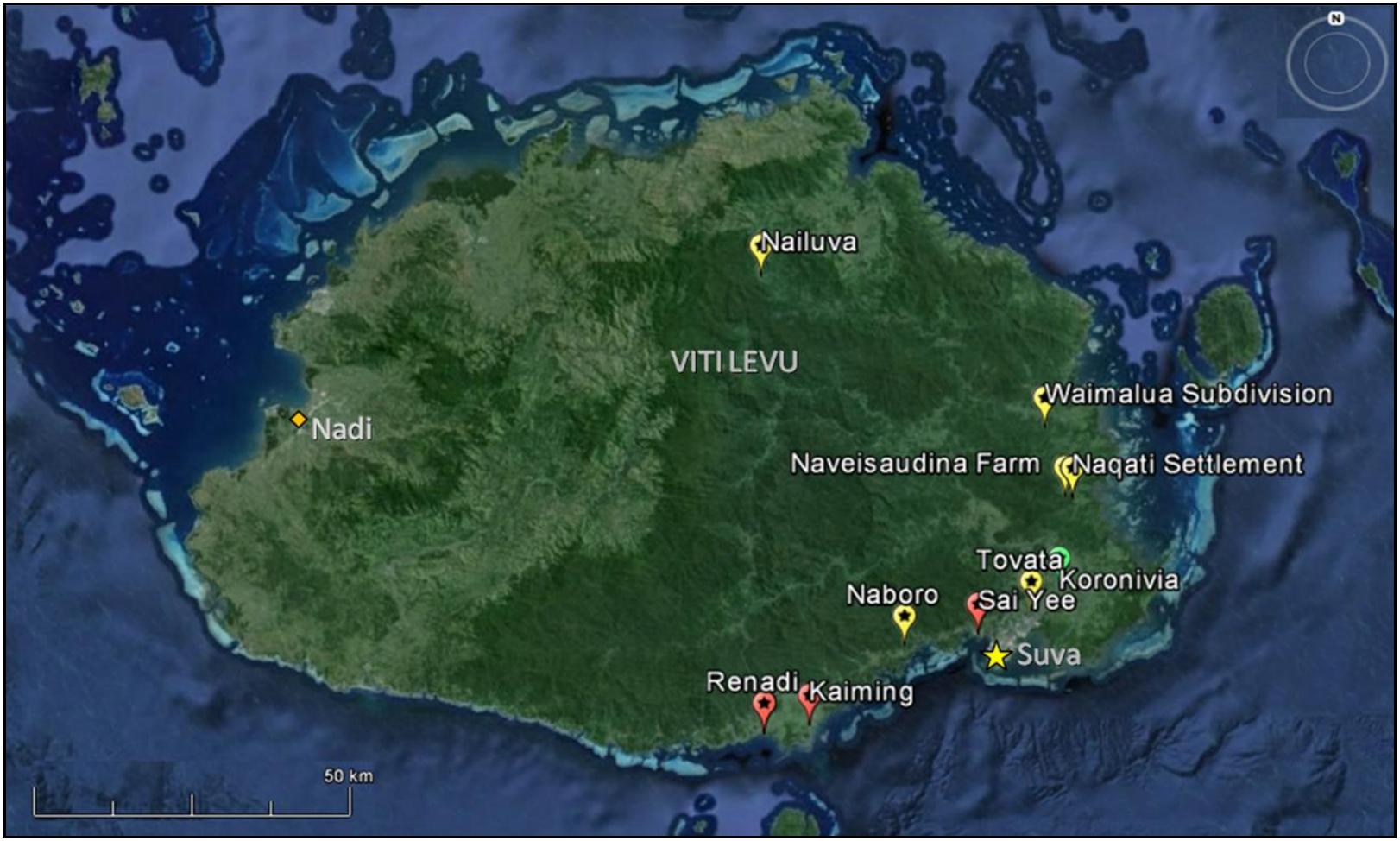
Ginger farms

- Tovata, Nasinu, Niatasiri
- Naveisaudina farm, Vugalei, Tailevu
- Naqati Settlement, Vugalei, Tailevu
- Waimalua Subdivision, Niatasiri
- Naboro Correction Complex, Naboro
- Nailuva Village seed nursery, Rakiraki

Packhouses

- Kaiming Agro Processing, Navua
- Ranadi Plantation, Deuba
- Sai Yee Foods, Lami

Figure 6 Location of ginger farms and packhouse facilities visited



Source: Google Earth

Field visit: Tovata

Figures 7 Ginger crop at Tovata

Figure 8 Ginger plants at Tovata

This farm is registered for export for the 2015 season. This is the first time growing ginger in this soil. Adjacent block planted with taro. Healthy plants, but some foliage was badly affected by rose beetle damage, with many holes in the leaves.

Field visit: Naveisaudina farm, Tailevu

Figure 9 Ginger crop being weeded by labourers at the Naveisaudina farm

Figure 10 Ginger crop at the Naveisaudina farm

This farm is registered for export. Ginger planted on at least three hillsides. Crop looked very good, consistent green colour, no yellowing to indicate disease problems. Workers observed manually removing weeds from crop. Some weeds, including crowsfoot, were evident. Taro and cassava are growing in other plots, and one plot was fallow. Pond is for fish farming, not for irrigation. A number of banana and plantain plants are growing around the property.

Field visit: Naqati Settlement, Tailevu

Figure 11 Hillside planted with ginger at the Naqati Settlement

Figure 12 Banana plant adjacent to ginger crop at Naqati Settlement

This farm is registered for export. Ginger planted on a steep hillside. This was a previously forested area, now planted with ginger for the first time. We were unable to observe the crop up close, but no areas of yellowing evident. Healthy banana plants were growing within and adjacent to the block of ginger.

Field visit: Waimalua Subdivision

Figure 13 Yellowing ginger plants at Waimalua Subdivision

Figure 14 Ginger crop at Waimalua Subdivision

This farm is registered for export. A number of plants had obvious yellowing of leaves, possibly caused by malnutrition. Mild symptoms of root knot nematode infestation were evident in the roots of one plant examined. Rhizomes and soil were collected for further testing. This area was previously forest, but was recently cleared for growing ginger for the first time.

Field visit: Naboro Correction Complex

Figure 15 Hillside planted with ginger at Naboro

Figure 16 Banana plants growing amongst ginger crop at Naboro

This farm is registered for export. Very healthy crop observed, uniform colour. This is the first time growing ginger on this land. Adjacent fields are growing taro and eggplant. Healthy banana plants are growing amongst the ginger crop.

Field visit: Ginger seed nursery, Nailuva village, Rakiraki

Figure 17 Ginger seed crop at Nailuva village

Figure 18 Ginger rhizome affected by Pythium soft rot

This farm is not registered for export production, but was established as a seed nursery to provide seed for local growers. This site is in a very remote location in the highlands, far away from other ginger production. Much of the crop appeared healthy, but some problems were evident. Pythium rot was seen in some rhizomes. Mild root knot nematode damage was also observed in the roots and rhizomes.

Packhouse visit: Kaiming, Navua

Figure 19 Washing rhizomes at the Kaming packhouse

Figure 20 Processing ginger at Kaiming

This facility is registered for handling export ginger. Kaiming is a major processor producing ginger products for the export market. It also handles fresh produce, including ginger. Ginger is washed, prepared, cured and packed on site. It has a large area set up for curing of ginger prior to packing. More than 100 staff are employed at the facility.

Packhouse visit: Ranadi Plantation, Navua

Figure 21 Conveyor for handling ginger prior to packing, Ranadi packhouse

Figure 22 Advisory signs identifying pest and quality issues, Ranadi packhouse

This facility is registered for handling export ginger. This facility only prepares ginger grown on the Ranadi Plantation, and does not accept ginger from other growers at this stage. Yam scale is a problem at this site. Very detailed crop management and record keeping were observed. Operations at the packing facility had temporarily shut down in preparation for the arrival of Cyclone Pam.

Packhouse visit: Sai Yee Foods, Lami

Figure 23 Packing room, Sai Yee Foods

Figure 24 Labelling for ginger packed for export

This facility is registered for the export ginger. Sai Yee is one of the main facilities handling fresh and processed produce from Fiji, and exported the first ginger consignment to Australia in 2014. Ginger is washed, prepared, cured and packed on site. Fumigation for export can be done on site by the accredited treatment provider.

Nematode research: Koronivia Research Station, Nausori

Figure 25 Screenhouse at Koronivia Research Station

Figure 26 Reniform nematode under the microscope at Koronivia

This is the Ministry's main research facility in the Central Division. Current research is focusing on the interaction of different nematode populations. Experiments underway in the screenhouse were looking at nematode resistance in taro and cassava. Facilities are basic and constrained by limited resources. Preliminary extraction of the nematodes in the soil sample taken at Waimalua earlier in the week were examined under the microscope and reniform nematodes were present (Figure 26).

Fumigation treatment provider: Amalgamated Pest Control

Figure 27 Demonstration of a ginger fumigation treatment

Figure 28 Safety sign for fumigation treatment

This is the only accredited fumigation treatment provider for export of ginger to Australia. Workers demonstrated a mock fumigation setup at Sai Yee Foods, showing the arrangement of boxes, location of probes and monitoring equipment.

Appendix 6 Ginger and its importation into Australia

This section provides a brief description of ginger, as well as an overview of the history of ginger in Australia and the evolution of policy for importation of ginger into Australia. This historical background provides the context in which contemporary import policy is situated, allowing a more informed understanding of the biosecurity risks associated with the importation of fresh ginger from Fiji.

Ginger: the plant, spice and commodity

The ginger plant

Ginger (*Zingiber officinale*) belongs to the Zingiberaceae plant family. This family of aromatic tropical plants also includes a number of other economically important species used for culinary, medicinal or ornamental purposes such as turmeric (*Curcuma longa*), cardamom (*Elettaria cardamomum*), red ginger (*Alpinia purpurata*) and torch ginger (*Etlingera elatior*). Ginger originated in southeast Asia, and has been cultivated in China and India since prehistoric times. It is now grown in most tropical and subtropical parts of the world (Ravindran and Nirmal Babu 2005).

The ginger plant is a herbaceous perennial monocot that is usually grown as an annual crop. The plant is slender and erect, around 30 to 100 centimetres in height, and has aerial shoots with numerous narrow leaves. The subterranean rhizome grows laterally close to the soil surface, and has many thin fibrous roots, and some larger fleshy roots (Ravindran *et al*. 2005). Ginger flowers are sterile, and the plant does not produce seed, so ginger must be propagated vegetatively. Pieces of mature rhizome with an apical bud are used for propagation, which are known as 'seed rhizomes'.

Climatic and environmental preferences

Ginger prefers a warm, humid climate, and cannot withstand very cold or very hot temperatures. The ginger root system is shallow, mostly within the upper 30 centimetres of the soil, and has low absorption ability (Xizhen *et al*. 2005). This means the plant grows poorly in dry conditions, and yield is significantly affected by low soil humidity. Excessive moisture also affects growth, as the plants are susceptible to root rot, so well-drained soil is required (Xizhen *et al*. 2005). Loamy soil is preferred, but ginger will also grow in arenaceous or clay soils. Ginger grows best in slightly acidic soils with a pH between five and seven (Xizhen *et al*. 2005).

Ginger varieties grown in Australia and Fiji

There are many different ginger varieties, with the greatest cultivar variation found in China (Ravindran *et al*. 2005). However, only a few varieties are grown in Australia and Fiji. The main cultivar grown in Australia for processing, known as 'Queensland', was originally introduced from China (Stirling 2004). This variety is also the most common variety grown in Fiji, where it is known as 'red' (Ministry of Agriculture 2013) or 'Queensland pink'. More recently, an induced tetraploid variety of 'Queensland' ginger was developed in Australia, known as 'Buderim Gold', which has higher yields and larger rhizomes (Ravindran *et al*. 2005), although it is not widely

grown at present. Tissue cultured Buderim Gold plants were introduced to Fiji (Smith *et al*. 2012), but this variety is not being grown commercially in Fiji.

The most common ginger variety grown for the fresh market in Australia is known as 'Canton', although small volumes of 'Queensland' and other varieties are also produced for consumption (Camacho and Brescia 2009). The 'Canton' variety, also known as 'white', is also grown in Fiji for the fresh market (Ministry of Agriculture 2013).

Ginger as a commodity

Ginger has long been used for culinary and medicinal purposes, and it is a major spice commodity in international trade. The international ginger market is highly segmented in terms of the source of supply and the end product, with three broad categories of ginger being traded: dried, preserved and fresh (McGregor 1988).

Dried ginger, typically traded as dried whole rhizomes or rhizome pieces, has always been the most important form of the commodity in international trade. India and China are the main suppliers of dry ginger (Madan 2005). Rhizomes are usually dried to moisture levels between eight and ten per cent (Balakrishnan 2005). Dry ginger can be used in food and beverage manufacturing, and for extraction of volatile oils and oleoresin.

Processed ginger is usually ginger pieces preserved in brine or syrup, or crystallized ginger. Immature ginger rhizomes are typically used for processed ginger products. Australia is a significant supplier of high quality processed ginger for the international market, and is the largest exporter of confectionary ginger products. Buderim Ginger exports sixty per cent of its processed ginger to overseas markets (Camacho and Brescia 2009). Exports of preserved immature ginger are also an important sector of the Fijian ginger industry (Gonemaituba 2008; Stirling *et al*. 2009).

Fresh ginger has traditionally been relatively insignificant in international trade, with small volumes exported from a limited number of countries. This is largely due to its perishability and limited seasonal availability (McGregor 1988). Fresh ginger is mostly used for oriental cooking (McGregor 1988). In recent years, consumption of fresh ginger in Australia has increased due to the growing popularity of Asian cuisine, and demand currently exceeds supply (Camacho and Brescia 2009). There are negligible exports of fresh ginger from Australia presently, although small volumes have been exported in the past (Camacho and Brescia 2009). Fiji exports around 1500 tonnes of fresh ginger annually, mostly into North America and New Zealand, although trade has fluctuated with competition from China, Brazil and Thailand (BAF 2012; Gonemaituba 2008).

A brief history of ginger in Australia and importation from Fiji

The history of ginger in Australia, including the development of the local industry, has been told extensively by Hogarth (1999) and Ryder (2010) previously. It is beyond the scope of this review to represent that full history here, but a few key events in the chronology are discussed as they help contextualise Australia's contemporary biosecurity policies within the broader historical picture. It is also relevant to highlight that trade in ginger from Fiji is not a new event, and modest volumes of fresh ginger were imported from Fiji into Australia in the past, both for human consumption and as planting materials. This is important when considering Australia's 'appropriate level of protection' while setting import policy.

Ginger in colonial Australia

The significance of ginger in Eastern food and medicine is well known, but it was also a highly valued spice in Britain and its colonies. By the 18th century, preserved ginger, gingerbread, ginger confectionary and beverages were popular in Britain (Ryder 2010). Its influence is reflected in the fact that ginger rhizomes and potted plants were carried with the First Fleet, and planted in the first garden in Sydney Cove in February 1788 (Ryder 2010). The botanist Joseph Banks sent further shipments of ginger plants from the Kew Royal Gardens to Sydney in the early years of the colony. Early attempts to grow ginger on any significant scale for commercial purposes were unsuccessful, although ginger was widely grown in home gardens (Ryder 2010).

The demand for ginger in Australia was predominantly for dried and preserved ginger, which was mainly sourced from China, Hong Kong and Jamaica. This processed ginger was mostly used for food and drink manufacturing, while fresh ginger was mainly used for jams and chutneys (Ryder 2010), as well as for cooking by the Asian migrant community. Local farmers could not produce and process sufficient ginger to meet demand, and so Australia was dependant on imports until after the Second World War.

The arrival of Chinese settlers in the latter 1800s, with their demand for fresh ginger and prominence in market gardening, saw small scale ginger production develop to supply local markets. Local production was supplemented with modest volumes of imported rhizomes, used for both human consumption and as planting materials. While much of the fresh ginger imported into Australia at that time was sourced from China, ship manifests indicate that small consignments (typically only a few sacks or cartons) of fresh ginger were sometimes imported from Fiji. It was reported that Fiji exported half a ton of ginger to the Australian colonies and New Zealand in 1891 (*Argus*, 28 June 1892). Fiji's ginger production at the time was predominantly from market gardens run by Chinese residents, and the export trade was facilitated by Chinese-owned trading companies in Fiji and Australia (Ng Kumlin Ali 2002).

Commercial ginger growing and establishment of the ginger industry

Some farmers began growing ginger in northern New South Wales in the 1890s, around Grafton, Lismore and Wardell, and this production persisted until after the Second World War, with limited commercial success (Hogarth 1999). Ginger plants were also widely distributed in Queensland by the Queensland Botanic Gardens and Queensland Acclimatisation Society. By the 1880s ginger was been commercially grown in Buderim and other parts of Southeast Queensland, the Burnett district (Maryborough, Bundaberg and Gympie) and near Cairns (Ryder

2010). Buderim became the centre of commercial ginger cultivation by the 1920s, although production later moved to nearby Nambour, Eumundi and Cooroy (Hogarth 1999).

Plantings remained only modest for many decades, as there was little market for locally grown ginger due to the lack of facilities to process it into a marketable product (*Nambour Chronicle*, 25 June 1926). This remained a significant constraint on commercial production until a processing factory was built at Buderim in the 1940s (Hogarth 1999). Food manufacturers typically required preserved or dried ginger rather than fresh ginger. By 1930 Australia was importing 1500 tons of ginger annually, consisting of around 1200 tons of ginger in brine or syrup, 300 tons of dried ginger and 20 tons of green ginger (Ryder 2010).

Until the 1950s, growers frequently relied on imported seed rhizomes for planting, as local supplies were often scarce. The crop planted at Wardell in 1940 was grown from seed ginger imported from Fiji (*Nambour Chronicle* 30 May 1941, p3). Planting material from Fiji was again used at Wardell for the following growing season (*The Land* 26 June 1942, p3).

Shipping restrictions during the Second World War significantly disrupted imports of ginger from China, providing an opportunity for local growers to supply the market (Hogarth 1999). Production increased from only 80 tons in 1942 to around 650 tons by 1950 (Ryder 2010). However, the industry had collapsed by 1952 due to increased competition following the resumption of imports after the war, and nematode and fungal disease problems in the crop (Hogarth 1999).

Attempts to revive the industry in 1954 were faced with the problem of obtaining sufficient planting material. China was considered the best available source, and thirty tons of seed ginger was imported from Canton (now known as Guangzhou) (Hogarth 1999; Pegg and Moffett 1971). Large areas of the crop were subsequently destroyed by a wilt disease, which at the time was attributed to an unidentified *Fusarium* sp. (Pegg and Moffett 1971). However, it is now believed that another pathogenic organism, *Ralstonia sequeirae* (synonym: *Ralstonia solanacearum* biotype 4) was likely responsible for the crop damage, and the *Fusarium* sp. isolated was only incidental to the disease (Hayward and Pegg 2013).

Disease management controls were subsequently introduced by the industry, although further bacterial wilt outbreaks occurred until 1976 (Hayward and Pegg 2013). It is highly probable that this pathogen was present in the seed rhizomes imported from China. As a consequence, strict controls on the supply of seed material were implemented, as were requirements for treatment of seed pieces prior to planting, crop rotation, weed suppression, disposal of crop waste and disinfection of farm implements (Hogarth 1999).

Quarantine controls on importation of ginger

The Commonwealth began regulating the entry of ginger rhizomes imported for planting purposes in 1957. The import conditions required all imported propagation material to be grown under quarantine conditions prior to release. Fresh and processed ginger intended for consumption was still permitted entry without restriction. Over the next two decades, significant quantities of fresh ginger were still being imported for further processing by the food manufacturing industry, as were small volumes for human consumption. During the period 1960–62, more than 205 tonnes of fresh ginger were imported into Victoria, with a further 83 tonnes imported into Queensland (Department of Health 1963). At the time, the Ginger

Marketing Board was concerned that ginger rhizomes imported for processing could be diverted for planting purposes (Department of Health 1963).

By the 1970s, the local ginger industry was firmly established and able to supply the market with sufficient fresh ginger to meet demand. At the time there were few quarantine restrictions on many fresh fruits and vegetables imported for consumption (with some notable exceptions, including bananas, citrus, apples and potatoes), but with growing import volumes there was increasing pressure for authorities to regulate this pathway. The importation of fresh ginger intended for human consumption was only prohibited in 1979 when *Quarantine Proclamation* 76P was legislated, which imposed regulations on the entry of all fresh fruit and vegetables. Under this proclamation, only frozen or processed ginger was permitted for human consumption purposes. Fresh ginger rhizomes were considered to be nursery stock, and were only permitted entry under the relevant import conditions (i.e. post-entry quarantine containment). No risk assessment was undertaken to substantiate this decision at the time.

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